Chronic Pain Management Serious Game Simulation UsingVirtual Reality and Brain Computer Interface

(Peripherals)

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*Abstract*— Brain computer interface (BCI) technology can be used to measure pain. Brain activity is recorded and analyzed using BCI devices. Electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) are two technologies that allow researchers to evaluate and study pain. EEG monitors electrical activity in the brain and has been used to identify neural activity patterns linked with various kinds of pain, including acute and chronic pain. BCI technology can provide an objective and precise measure of pain, potentially leading to better pain management methods for people experiencing pain. More study in this field is required to find out how Virtual reality can be utilized in this field. However, further research is needed to validate the use of BCI technology as a reliable measure of pain in different populations and clinical settings. In this study, we review and study different methods of measuring pain using BCI.

This technology enables researchers to observe and evaluate pain-related neural activity in real time. This could lead to the identification of neural patterns linked with pain, which could then be used to develop personalized therapy strategies for each patient. Furthermore, we could combine this technology with virtual reality to make a simulation that can monitor the patient's pain experience and assist with further therapy. This will provide a safe and controlled environment for patients to better understand their pain and learn the coping mechanisms by allowing patients to interact with and control the simulation using their brain activity. In addition, using virtual reality (VR) to create immersive training experiences for patients to enhance their mobility and agility. By designing training scenarios that mimic real-world tasks, such as playing a music with a music box, petting a pet or gardening, we can help patients regain their confidence and independence while managing their pain in a controlled environment. Overall, the combination of brain computer interface and virtual reality technology has immense potential to revolutionize the way we treat chronic pain. Chronic pain is a serious health issue that affects millions of people worldwide, and there is a great need for innovative solutions that can help manage this condition. This study aims to research and develop a serious game and simulation by combining two innovative technologies, virtual reality, and brain computer interface to understand patients’ needs better and assist them with their chronic pain recovery and ease their pain. The game will provide patients with an immersive and interactive experience, allowing them to engage in activities that can help manage their pain, such as meditation, relaxation exercises, and cognitive-behavioral therapy.

Keywords—BCI, VR, Pain, Chronic Pain, EEG

# Introduction

EEG measures pain by recording electrical activity in the brain. When a person experiences pain, different parts of the brain become activated, which can be detected by measuring the electrical signals generated by the brain using electrodes placed on the scalp. The EEG signal is typically analyzed in the frequency domain, which involves breaking down the signal into different frequency components using mathematical techniques such as Fourier analysis. Different frequency components are associated with different types of brain activity, such as alpha, beta, delta, and theta waves.

## Signal Acquistion is the

Research has shown that different patterns of EEG activity are associated with different types of pain, such as acute pain and chronic pain. For example, acute pain is associated with an increase in high-frequency beta waves, whereas chronic pain is associated with changes in the low-frequency alpha and theta waves. EEG can also be used to measure the effects of pain medications and other pain management strategies on brain activity, which can provide insights into how these treatments work, how they can be optimized and how effective the simulation and trainings are.

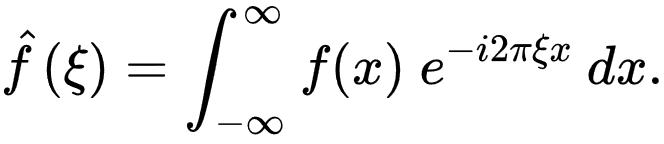
Fourier analysis is a mathematical technique that is commonly used to analyze EEG signals in order to measure pain. This technique involves breaking down a complex signal into its component frequency parts, which can help identify patterns of neural activity associated with pain.

To perform Fourier analysis on EEG signals, the signal is first divided into small segments, typically around one second in duration. These segments are then transformed from the time domain to the frequency domain using a Fourier transform algorithm. This produces a power spectrum, which shows the strength of each frequency component in the signal.

Research has shown that certain frequency components of the EEG signal are associated with pain. For example, acute pain is often associated with an increase in high-frequency beta waves (around 20-30 Hz), whereas chronic pain is associated with changes in the low-frequency alpha and theta waves (around 4-8 Hz and 4-7 Hz, respectively). By analyzing the power spectrum of the EEG signal, researchers can identify these patterns of neural activity and use them to measure pain.

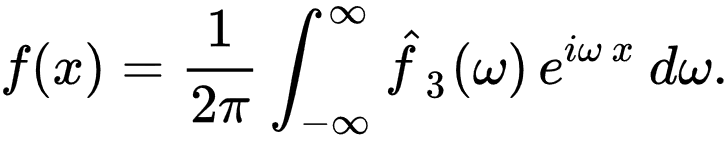
The mathematical formula used for Fourier analysis is called the Fourier Transform (FT). There are different types of Fourier transforms, such as the Discrete Fourier Transform (DFT) and the Fast Fourier Transform (FFT), but they all use similar principles.

The Fourier transform converts a signal from the time domain to the frequency domain, by decomposing the signal into a sum of sine and cosine waves with different frequencies. The formula for the Fourier transform is:

(1)

where F(w) is the frequency domain representation of the signal, f(t) is the time domain signal, w is the angular frequency (in radians per second), and i is the imaginary unit.

The inverse Fourier transform is used to convert a signal from the frequency domain back to the time domain, and its formula is:

 (2)

where f(x) is the time domain signal, F(w) is the frequency domain representation of the signal, and 1/2pi is a normalization factor.

In practice, these formulas are implemented using numerical algorithms, such as the FFT, which allows for efficient computation of the Fourier transform.

The FT, FFT, DFT and their respective inverse function gives us information in both the time and frequency domain.

## Research shows there are different methods to determine and measure the pain. Followings are some of the methods we discuss and experiment in this study:

### Use band-range correlation to determine pain: Make an educated guess of what frequency ranges which will constitute the pain (Gamma and delta) and make a correlation graph based on those channels. This method may not be accurate and may result in low accuracy.

### Use networks of electrodes which correlate with pain: Make an educated approximation of what sensors (P1, FP2 etc) affect pain the most and create a correlation graph depending on the chosen sensors.

### Both at the same time: Specifics of this approach must be worked out properly, channels to work on are the frontal sensors FP1 and FP2, parieto-occipital area P3 and P4.

In a timeline during the experiments with patients with phantom pain, pre and post experiment’s questionnaire is required to confirm and verify the data.

## Sensors and channels brief explanation:

The 10-20 system is an international system for electrode placement on the scalp. “10” and “20” refers to the distances in percentage between the electrodes in relation to the width and length of the head. The name of each electrode is defined by the area of the scalp it is on. The scalp is divided into 6 areas: Frontal, Central, Parietal, Occipital and Temporal (right and left). The electrodes names are defined by the area of the scalp. and with an odd or even number defined by whether it’s on the left(odd) or right(even) side.

Fig1 illustrates the 10-20 system and electrode placements:

Diagram

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Figure : Brain channels

## Pain Detection

Detecting pain with EEG data is an elusive goal. Different types of pain occur differently in the brain (REFRENCE HERE; I DON’T REMBER THE ARTICLE). Much research has and is being done in this field.

Seeing an increase in beta, delta and gamma waves. Decrease in alpha waves. Activation of frontal sensors (FP1 and FP2),

Acquiring the FFT’s is easy, these can be outputted by the OpenBCI GUI and imported wherever we like.

“Although no robust EEG biomarkers of pain perception have been identified yet, EEG has potential and future research should be attempted. Designing strong research protocols, controlling for potential risk of biases, as well as investigating brain networks rather than isolated cortical changes will be crucial in this attempt.”

Key points:

An increase in the delta power activity is observed in standard EEG during pain.

An increase in the gamma power activity is observed in standard EEG during pain.

EEG has potential as biomarker of pain perception

Investigating brain networks rather than isolated cortical changes is important in future studies.

This study goes over the correlation between alpha to gamma waves and pain.

Delta activity: Conflicting studies however this likely has some correlation with pain.

Theta activity: Contradictory studies, no correlation.

Alpha activity: Decrease in the parieto-occipital areas of the brain is one of the most common correlations with pain. The parieto-occipital area is “back of the head” kinda.

Beta activity: An increase of the beta activity, mainly temporal areas, has been reported in almost all studies.

Gamma: Many studies have found that an increase of gamma correlates to pain, however varying greatly. The gamma oscillations at the frontal or frontocentral electrodes encoded the subjective intensity of pain, showing a positive correlation.

They conclude that increases in Gamma or Delta waves have the highest potentials for being biomarkers for pain perception. Looking at networks may be more effective than going range based.

Brain Rhythms of Pain: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5374269/pdf/main.pdf>

Notes on DRoP :

Quote from conclusion. “It has been shown that there is no one-to-one correspondence between oscillations at any frequency or location and the subjective experience of pain, which extends evidence on the lack of specificity of pain-related brain activity [15] to the frequency domain.”

BCI training to move a virtual hand reduces phantom limb pain :

<https://n.neurology.org/content/neurology/95/4/e417.full.pdf>

Notes on BtVHtRPLP:

Quote from conclusion: Three-day training to move the hand images controlled by BCI significantly reduced pain for 1 week.

They used Questionnaires only to measure pain.

Scalp EEG-based pain detection using cnn

<https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9696316>

Has a “Significance of Brain Areas” section. Great.

“Unlike other sensations associated with specific areas in the brain, such as vision, touch and hearing, it is hard to find studies reporting specific cortical area activations dedicated to pain with different kinds of simulations.” The study finds that there is barely any difference in how important different sections of the brain is for pain. This matches the other studies but also includes a sidenote about the Motor-Occipital parts of the brain outperforms the other areas. This is good because it correlates with the other research finding T7 and FC5 to be the best candidates.

Important Quote: “If the conditions are insufficient for brain area selection in pain detection, e.g., limited channels, unknown evoking areas, the safest way for EEG-based pain detection is to employ all EEG channels. However, if the stimulation and the activation area(s) are evident, a subset of channels covering specific brain areas should be considered for achieving better detection accuracy at a lower computational cost. Results in this work may provide a new solution and insights for researchers and clinical practitioners for pain detection.”

This recommends (kinda, we’re kinda half-n-half) the approach I wrote earlier about trying to mix frequency ranges with specific electrode selection.

(FORMATTING LOST BELOW, INDENT IN NEW LINE, IDK HOW TO ENABLE IT, USING REGULAR TAB)

# The Game

Peripheral is a game and BCI. It is made using Unreal Engine 5 (UE). The game lets the player control game mechanics with their mind. This is achieved through custom Python and C++ code running simultaneously and transmit data to UE. The game supports VR, but can also be played non-VR. The game can also be played with and without mind control. This allows for the game to be utilized in several ways and accommodate for different players and research teams. With a VR headset that support hand-tracking(Ref). Peripheral supports X, Y, Z VR headsets and X,Y,Z BCI headsets.

# Metodology

## Pain detection Method :

Condition: Beta wave increase in temporal areas - T7 - FC5 - T8 - FC6

* Method 1:

Track average Beta voltage for the task period:

 (B\_T7 + B\_FC5 + B\_T8 + B\_FC6) / 4 (3)

Did the average go up the last 30 ms?

Delta Power = Current Average - Last Average

A high delta power fulfills the condition.

* Method 2:

Per node method. We track T7, FC5, T8 and FC6 over the task period.

Store average power of a set time steps.

TimeStep - NextTimeStep = Delta Average Power (4) →

We now have four Delta Average Power

Chart, line chart

Description automatically generated

Figure . Beta waves cycle in 30ms

# Ease of Use

# Prototype and design

## Headset Design

In this study, we have tried different way to combine VR and BCI data acquisition and synchronize feedbacks and data. There are some limitations due to lack of the technology at the moment that does not allow us to use both of these technologies at the same time. There are however companies like OpenBCI that are working on a device called Galea (<https://galea.co/#home>) that will suit this purpose; however, the headset is still not available in market. To overcome this issue and limitations, we designed a new headset that allows us to put both headsets together.

There are some design choices that we needed to make in order to make the headsets work well for this project. As we try to detect the user’s pain, we added RGB light to the headset, and program the system in a way to alarm the conductor of the simulation to know when the user feels the pain.

## Car Game

To gather the data in a manner that we can sync the pain data with other signals for analyzing, we designed and implemented a feedback switch that the patient will hold in one of their hands. This way, when they feel the pain, all data will be synced and helps the measurements to be more accurate. This also will help with calibration of the system. For VR gameplay a button on the hand-controller acts as this feedback switch.

Fig3. Illustrate the prototype design of the headset, which will be using OpenBCI biosensing board and electrodes. As for the VR headset we will be using Meta quest 2.

A picture containing wheel

Description automatically generated

Figure BCI headset Placeholder

## Lobby design

Why do we have a lobby ? Why is the way it is? What do we gain from it?

## Music and color pallete

## Levels / Game? Design

#### Level 1 : Wood Stacking

*(TEMPORARY;* THIS IS NOT GOOD)

#### Study show that wood logs is an activity that triggers an emotional reaction in Norwegians. We employ this as a level. This level is the first step on the difficulty ladder.

#### Level 2 : Music Box

Music is a widely used tool for therapeutic treatment (Refs). This level requires finer control by the player are is therefore more difficult. The

#### Level 3 : Animal Petting

Engaging with a friendly animal illicit emotional responses in us(NEED RESEARCH HERE). This level provides the player with an animal companion. The animal can be interacted with in several ways. The animal responds to the player’s prompts. The player can throw a ball and the animal will run, fetch and return it.

#### Level 4 : Painting

#### Level 5 : name of level 5

## Results and discussion

# conclusion

##### Acknowledgment

##### References

1. G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. *(references)*

# Ease of Use

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* Do not mix complete spellings and abbreviations of units: “Wb/m2” or “webers per square meter”, not “webers/m2”. Spell out units when they appear in text: “. . . a few henries”, not “. . . a few H”.

Identify applicable funding agency here. If none, delete this text box.

* Use a zero before decimal points: “0.25”, not “.25”. Use “cm3”, not “cc”. (*bullet list*)

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*a**b* 

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* There is no period after the “et” in the Latin abbreviation “et al.”.
* The abbreviation “i.e.” means “that is”, and the abbreviation “e.g.” means “for example”.

An excellent style manual for science writers is [7].

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1. Table Type Styles

| Table Head | Table Column Head | | |
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| Table column subhead | Subhead | Subhead |
| copy | More table copya |  |  |

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Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity “Magnetization”, or “Magnetization, M”, not just “M”. If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write “Magnetization (A/m)” or “Magnetization {A[m(1)]}”, not just “A/m”. Do not label axes with a ratio of quantities and units. For example, write “Temperature (K)”, not “Temperature/K”.

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