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

Acute Pain Detection Using Serious Games, Virtual Reality and Brain Computer Interfaces

Preface: I’m not married to the title, just a suggestion. I feel having Pain, SG, VR and BCI in the title is important. I think “Chornic” pain is wrong because we’re not doing an experiment with participants who have chronic pain and study their brain waves. We’re detecting acute pain. Most places where I write (studies) or (refs) I already have them somewhere on docs but I’m not bothering finding them while I’m writing.

(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 voltages and can be used to measure 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.

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.

EEG offer great temporal resolution, many EEG devices being able to record 250 Hz and greater. Fourier analysis is a mathematical technique that is commonly used to analyze EEG signals in order to reduce the complexity in analyzing the data. 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.

Articulate that we’re using SG and VR to immerse the player more and hoping that it will benefit the BCI. In limitations we can state that we originally intended for phantom pain research which would utilize VR on whole different level.

VR has been shown to have be able to change brain chemistry and brain activity (STUDIES).

Serious games have large potential for society (STUDIES). Many fields have been shown to greatly benefit from serious games. Medicine and education are two fields which greatly employ serious games (STUDIES).

Pain is an elusive subject in neuroscience (STUDIES). The brain’s systems for pain are not yet well understood. Much research is being done and modern technologies and methodologies are driving the field forward.

Research has shown that certain frequency components of the EEG signal are associated with pain.

# Background

This section goes into further detail about some of the subjects already mentioned.

## Brain Computer Interfaces

BCIs are commonly divided into five steps:

### Signal Aquistion

The signal is acquired trough EEG on the scalp. EEG records the voltages created from the electrical signals in the brain.

### Signal Preprocessing

The signal we get often contain noise and unwanted artifacts. The noise comes from many sources: the scalp, surroundings, heartbeats, eyeblinks, machines and more (Elsayed et al. 2017).

### Feature Extraction

The signal has now had noise and artifacts removed. If we for example have 16 electrodes recording at 256 Hz for 10 seconds, we get a lot of data. All this data is not useful for us and therefore we extract these features.

### Feature Classification

Feature Classification refers to classifying a feature from the signal into meaningful data. This is achieved through many different methods from machine learning (ML) to visual analysis of the signal.

### Feedback

This step is where the computer executes the command from step (4). This often result in feedback to the user.

## Electroencephalography

We use the “10-20” system electrode placement. This is an international system for standardizing electrode placements. Standardization is important for electrode placements. It ensures we measure signals at the same places on the scalp as other researchers do. The systems labels electrodes by the area of the scalp and whether it’s on the left or right side. Electrodes on the left side of the scalp use odd numbers and the right-side use even numbers. The scalp is divided into sections: Frontal, Temporal (Left and right), Parietal and Occipital.

PICTURE

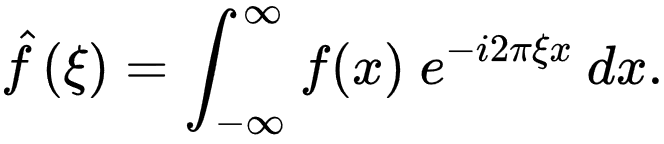
## Fourier Transform

Feature Extraction is often done using the Fourier Transform. The Fourier Transform converts the signal from the time domain into the frequency domain.

For example, acute pain is often associated with an increase in high-frequency beta waves (reference here), whereas chronic pain is associated with changes in the low-frequency alpha and theta waves (reference here). By analyzing the power spectrum of the EEG signal, researchers can identify these patterns of neural activity and use them to measure pain.

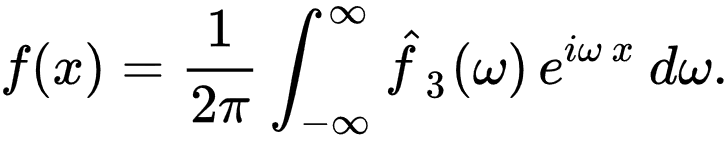
The mathematical formula used for Fourier analysis is called the Fourier Transform (FT). There are different types of Fourier transforms, such as the Discrete Fourier Transform (DFT) and the Fast Fourier Transform (FFT), but they all use similar principles.

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 the frequency and the time domain respectively.

The Short-Time Fourier Transform (STFT) gives us the time-frequency domain. Using the STFT lets us analyze when frequency artifacts occur. This enables us to analyze data and look for artifacts which would be impossible to spot without the time-frequency domain.

## Pain Detection

Hence identifying pain using EEG is not a a

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. Chronic pain is being shown to correlate with specific brain signals (STUDIES EHRE; I GO THEM ON DOC). Being able to detect pain trough EEG can provide great benefits.

Studies doing pain detection from EEG signals often use self-reported scales, like a Visual Analog Scale (VAS), to obtain information about the pain an experiment-participant experience. We attempt this through a compilation of information gathered from similar articles.

(Reference; I don’t remember name, but it’s a specific article I have linked on my doc) show many studies show differing results and sometimes contradictory results.

We reference several studies with experimental results (list here). We have compiled a set of signal-artifacts from the studies. We refer to these each artifact of these as a Pain Indicator (PI). The following subsections will cover the PI’s we use.

### 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.

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

This study reports what brain areas contribute the most.

<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.

# Metodology

## Motor Imagery

(Disclaimer: This is not true and has not and may never be done).

We employ a CNN to classify between four MI tasks: left, right, up and down.

A “Adam” qualifier is used with a ReLu activation functions. The CNN consist of x layers with 3 pooling layers and a fully-connected layer as the classification layer.

## Pain Detection

The PIs we have chosen blabla.

### Pain Indicators

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 . Example for 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.

## 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

.

### Level 1 : Wood Stacking

*(TEMPORARY*)

#### 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 includes a music box with a handle. Turning the handle makes music play for the player. This level requires finer control by the player and therefore is therefore more difficult than the previous level.

KEEP IN MIND TO LOOK OUT FOR IF THIS LEVEL WORKS VERY WELL, IT MAY HAVE SOMETHING TO DO WITH THE MUSIC FEEDBACK IMMERSING THE PLAYER.

### Level 3 : Animal Petting

Engaging with a friendly animal illicit an emotional response in many people (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

This level gives the player the ability to paint. (REFRENCE TO STUDY OR SOMETHING SAYING PAINTING IS GOOD)

# Limitations

(I don’t know if this is stuff we should even mention, but I think it’s appropriate) Many studies that use a “literature review”, kinda what we’ve done with pain, they state how they qualified what studies to use. Removing this is fine

## Qualifications

Under-graduate degrees in “Game and Simulation-technology” and “Animation and Digital Art”.

## Qualifying Studies and Results

As stated in the previous subsection, the team does not have formal qualifications in biological sciences. Therefore, we cannot attest to the quality of the studies referenced and methodologies used for pain analysis.

# Results and discussion

## Results from CNN classification

Our CNN algorithm was able to predict with 100 000 000% accuracy( one hundred million percent). This will revolutionize the field and we have been given offers > 100 000 000 000 kr. Email now to send your offer.

## Results from Pain Detection

### P4 Beta Wave correlated with VAS

Pearson graph here

### TC5 Gamma

### Etc

## Intra-task Reported Pain

In this section of the results the STFT graphs must be analyzed and compared to when the user pressed the pain-button.

# conclusion

We have conducted a literature review and generated a list of PI’s which we use to determine pain in the participants.

# Acknowledgment

We would like to thank Daniel for his 3D printing expertise.

# 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.
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3. *(references)*

# Ease of Use

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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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The equations are an exception to the prescribed specifications of this template. You will need to determine whether or not your equation should be typed using either the Times New Roman or the Symbol font (please no other font). To create multileveled equations, it may be necessary to treat the equation as a graphic and insert it into the text after your paper is styled.

Number equations consecutively. Equation numbers, within parentheses, are to position flush right, as in (1), using a right tab stop. To make your equations more compact, you may use the solidus ( / ), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

*a**b* 

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## Some Common Mistakes

* The word “data” is plural, not singular.
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* Do not confuse “imply” and “infer”.
* The prefix “non” is not a word; it should be joined to the word it modifies, usually without a hyphen.
* 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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Text heads organize the topics on a relational, hierarchical basis. For example, the paper title is the primary text head because all subsequent material relates and elaborates on this one topic. If there are two or more sub-topics, the next level head (uppercase Roman numerals) should be used and, conversely, if there are not at least two sub-topics, then no subheads should be introduced. Styles named “Heading 1”, “Heading 2”, “Heading 3”, and “Heading 4” are prescribed.

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1. Table Type Styles

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The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

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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)*
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7. M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.

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