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Music Therapy with Neurofeedback in Palliative Treatment of Advanced Cancer

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Abstract

Advanced cancer patients in palliative care often go through non-invasive forms of therapy for pain relief and improving quality of life. Patients benefit from both passive and active music therapy, wherein they can listen to or participate in playing their favourite music with a trained therapist. In combining music therapy with neurofeedback, and using the patient's live EEG signals to change the musical parameters of a song, we can test the effect of neurofeedback and entrainment on patients' well-being and emotional state. To test the effect of adding an entrainment relaxation session, seven sessions of music therapy were conducted: five sessions for an experimental group which received neurofeedback entrainment, and two sessions for the control group which received passive music therapy without entrainment. A Muse headband device was used to collect EEG data, and a live graphical interface was developed to display the patient's live arousal level. We then perform a quantitative analysis using the recorded EEG files, calculating arousal and valence levels throughout the sessions to reflect the patient's emotional state. We also analyze the qualitative data from patient questionnaires and verbal feedback to determine the impact of the session. The contextual analysis of each individual session showed positive results and feedback from the patients. The recorded EEG data showed overall trends of lowered arousal levels in the experimental group, who participated in the entrainment sessions, and higher valence levels in the control group, who received passive music therapy.

Keywords: Neurofeedback; Music therapy; Palliative care; Entrainment.

Chapter 1

Introduction

The combination of music therapy with neurofeedback is a fairly new area of research being tested on patients with different conditions. The idea behind this study is to determine whether music being played in sync with the patient's electroencephalography signals will provide better results than 'traditional' music therapy, without this synchronization. The following section will introduce the topics used in this research project, such as music therapy techniques and neurofeedback.

1.1 State of the Art

In recent years, there has been an overall shift towards non-invasive forms of treatments for various different illnesses and conditions. More effort is being placed into building infrastructure for therapy programs and other less 'traditional' forms of therapeutic care, rather than relying solely on pharmaceutical treatments. Musical neurofeedback is a novel form of non-invasive therapy which combines music therapy and neurofeedback therapy. It provides the patient with a musical interface through which they can control their brain activity; their brain waves are mapped to parameters - such as tempo, volume, and tonality - in the music that they hear in real time. The following subsections will define and explain the relevant topics to this study: music therapy, electroencephalography, brainwaves, emotion classification, and neurofeedback therapy.

1.1.1 Music Therapy

Music therapy is becoming more prevalent and is often used in rehabilitation programs as well as hospitals and nursing homes to aid in patient healing [1]. The goal with music therapy is to improve the patient's mental state or overall quality of life. For certain conditions, music therapy can also alleviate symptoms entirely. There have been impressive results in improving patient conditions for various different types of illnesses, such as clinical depression and schizophrenia [1]. Music therapy can also be used to lower pain perception, and reduce incidences of nausea, anxiety, and delirium in patients with advanced cancer or those undergoing major surgeries [2]. The two main types of music therapy are passive, or listening-based, and active, where the patient is participating in playing the music themselves [3].

Within the field of music therapy, there exist many different techniques that work towards different goals. Relaxation is a common goal with music therapy, in dealing with patients in distress or with high anxiety levels. One of the most popular relaxation techniques is entrainment. In music therapy, entrainment consists of synchronizing music with the patient's biosignals, such as heartbeat, breathing, or brain activity. In combining music therapy with neurofeedback in an active session, the patient to control the music through their own brain activity [4]. In a passive session, the music therapist can use entrainment to synchronize the music to the patient's brain activity without the patient attempting to control the music.

1.1.2 Electroencephalography

The central nervous system is comprised of two types of cells: neurons and glia. Most neurons are connected to multiple other neurons, and are able to communicate with each other using electro-chemical signals that are transmitted from one cell to another. The changes in electrical potential that occur from the transferring impulses are called *action potentials*. Action potentials range from 20 to 30 millivolts and occur very rapidly, however, the summation of billions of action potentials occurring in the brain can be measured at the scalp using electroencephalography

(EEG) sensors [5]. The complex rhythmic electrical activity of thalamo-cortical circuitry has been researched for decades in order to develop a model for EEG that can be used for neurophysiology research [5]. A standard for optimal electrode placement was developed by Herbert H. Jasper in 1958 called the 10-20 International system of electrode placement. Figure 1 shows the standard's suggested electrode placement, which corresponds to the cerebral cortical regions. [5] The letters used to annotate the placements are used in descriptions of almost all EEG devices available on the market.

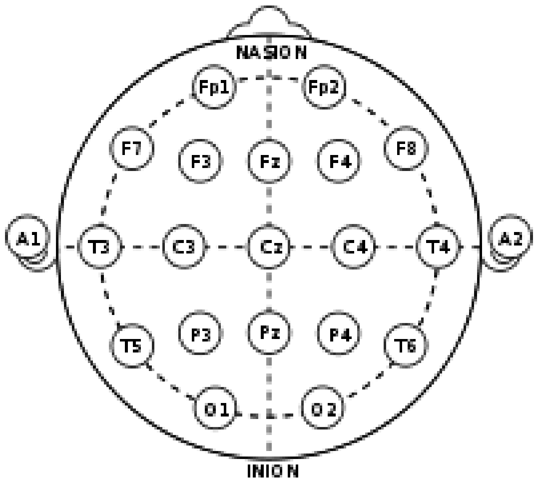


Figure 1: Diagram showing the 10-20 International System of Electrode Placement. The letters correspond to the regions of the cerebral cortical regions (Fp = frontal pole, C = central, P = parietal, O = occipital). Odd numbers correspond to the left hemisphere, and even numbers correspond to the right hemisphere.

Although there exist much more precise techniques for the measurement of cerebral activity, such as computed tomography (CT) and functional magnetic resonance imaging (fMRI), EEG remains the best option for studies such as the one described in this paper for several reasons. For instance, EEG scans do not produce noise, making it ideal for studies concerned with measuring the effect of auditory stimuli. Second, there are low-cost options for EEG devices, that do not compromise the reliability of the data and are physically easier to set up remotely.

1.1.3 Brainwaves

There exist many forms of processing that can be done with EEG signals, such as analysis of event-related potentials (ERPs) such as blinks or eye movements, or in brainwaves. The rate of repetition of electrical signals firing can be measured and categorized into measured brainwaves. Brainwaves are measured in Hertz (Hz), or cycles per second, and are usually categorized into five types. Figure 2 shows the five types of brainwaves, categorized by their frequency bands and amplitudes. These five brainwaves are indicators of certain mental states of thought or experience. For example, alpha brainwaves are associated with wakeful relaxation, and beta waves are associated with alert consciousness or excitement.

Using EEG measurement devices and Brain-Computer Interfaces (BCIs), brainwaves can either be displayed on a scrolling line graph (i.e.: displaying the live measurement), or presented as a bandpower. Frequency bandpowers can be expressed in two ways: absolute or relative. Absolute bandpowers can be calculated as the logarithm of the power spectral density of the measured EEG. The resulting value will be given in Bels, on a logarithmic scale [7]. Relative bandpowers are expressed as a ratio of a specific frequency band's absolute power over the sum of the total bandpowers in that instant. This results in a value between 0 or 1, but will never reach 0 or 1 [7].

1.1.4 Emotion Estimation

Brainwaves can be used to derive useful information about mental activity, namely in emotion estimation. There are equations that have been derived to denote relationships between brainwave bandpower and the emotional state of the patient. One of the most popular dimensional models of human emotions is the circumplex model of arousal and valence, developed by James Russell in 1980. [8] This model graphs human emotions on a two-dimensional plane showing *arousal* on the y-axis and *valence* on the x-axis. Figure 3 shows a basic representation of the circumplex model.

A patient's instantaneous arousal and valence levels can then be expressed as nu-

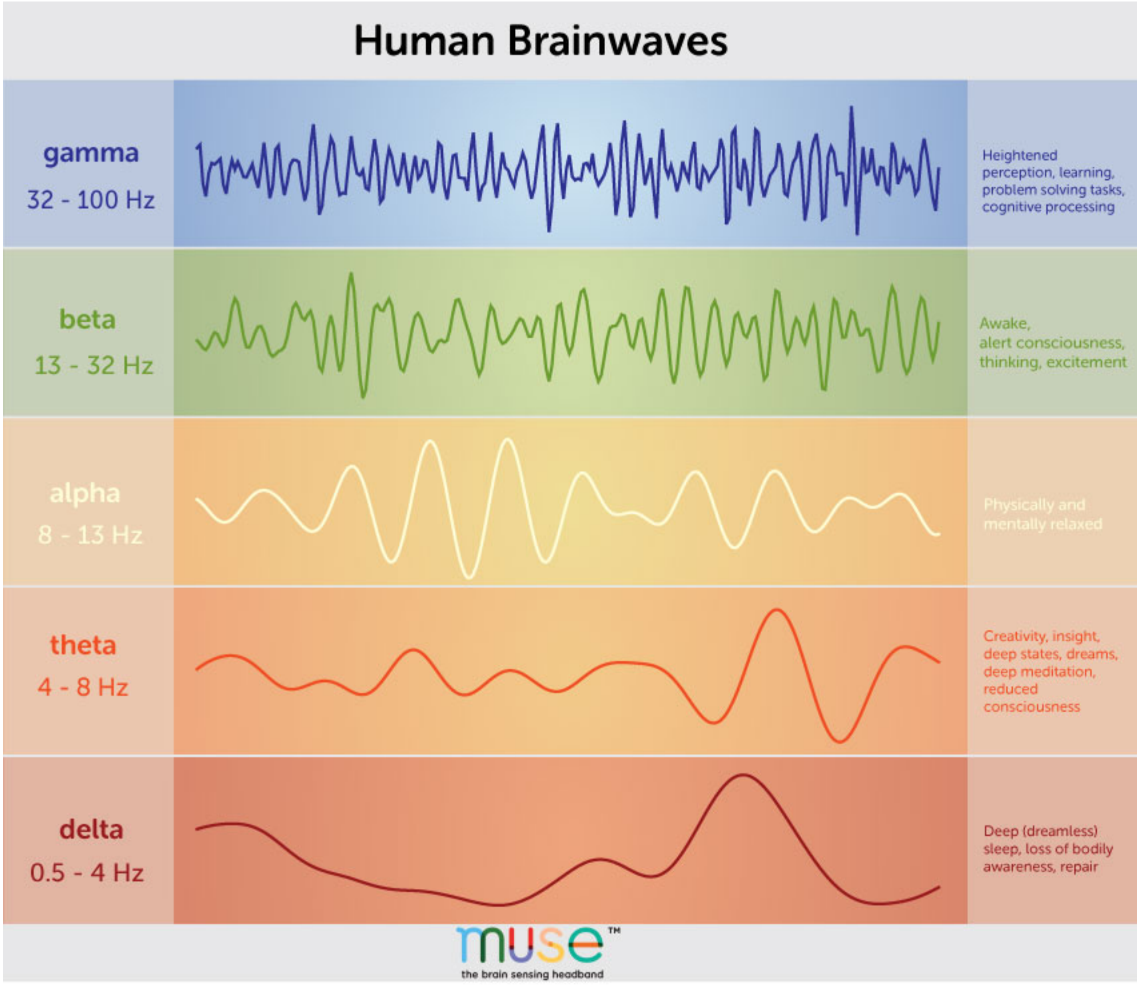


Figure 2: Graph showing the five types of brainwaves, categorized by frequency band. The first column shows the brainwave name and associated frequency band. The third column contains brief descriptions of the mental states typically associated with these brainwaves. [6]

merical values ranging from negative to positive scales. Most commonly, they can be derived using the instantaneous alpha and beta brainwave bandpowers, or alpha brainwave bandpowers alone. The equations used to compute arousal and valence in this project will be described further in Section 2.1.5. Various studies in emotion estimation have used alpha and beta brainwave bandpowers and the circumplex model in their estimation, such as [4], [9], and [10].

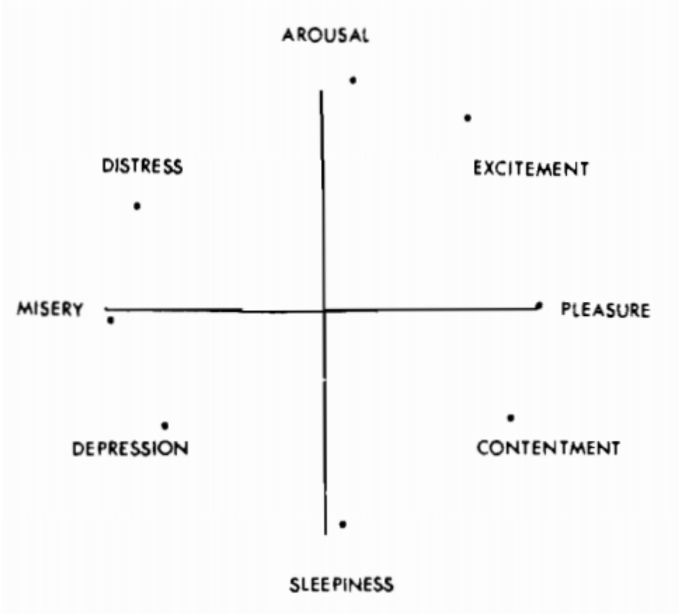


Figure 3: Graph showing a basic version of the circumplex model of human emotion, developed by Russell in 1980. [8]

1.1.5 Neurofeedback Therapy

Neurofeedback consists of a loop where a patient's EEG signals are fed in real time to a computer interface. In a visual feedback system, the patient can then see their actual brain wave signals on the interface and can actively try to control them. In an audio feedback system, the patient's live signals are processed to control audio parameters of a sonic environment (e.g.: nature sounds or music) and the patient uses the sonic cues to control the signals. Figure 1 illustrates a basic neurofeedback loop, with combined audio and visual feedback.

There are many different types of neurofeedback therapy, and many of them rely on audible interfaces for the user, where the EEG signals are mapped to sounds that the user is intended to control. Recently, neurofeedback has risen in popularity thanks to technological advancements that have led to EEG devices and Brain-Computer Interfaces (BCIs) to be available for purchase to the public at low-cost and in easy-to-use forms, such as Bluetooth headbands [12]. There have been numerous studies showing the positive effects of neurofeedback on patients with mental illnesses such as attention-deficit hyperactivity disorder (ADHD) [13], depression [14], anxiety [14],

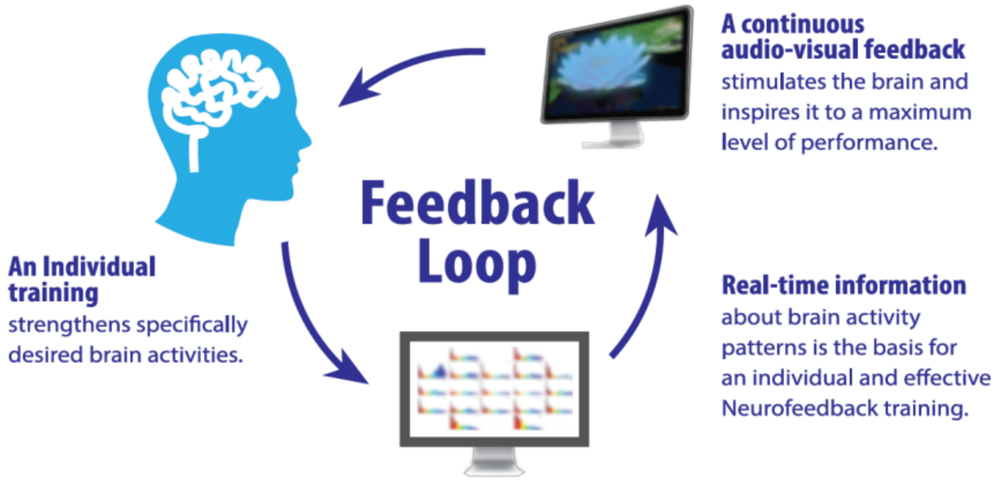


Figure 4: A basic neurofeedback loop with audio-visual feedback. [11]

and late-stage cancer [15].

1.1.6 Non-invasive Therapy for Advanced Cancer Patients

The treatment methods in place for patients with advanced cancer, including surgery, chemotherapy, and radiation, often have lasting side effects and impact on the patients. For instance, chemotherapy and extended time under anesthesia can cause a decay of healthy neurons in the patient's brain [15]. It has been shown that neurofeedback therapy sessions have a positive impact on the effects of chemotherapy and anesthesia on the brain [15].

Other side effects can have detrimental impact on the patient's mental health, and cause increased episodes of delirium, anxiety, and depression [2]. Delirium is an acute confusional state and clinical syndrome that largely affects people of 65 or older [16]. It can affect patients in postoperative care, intensive care, or palliative care. Studies have shown that, with passive music therapy sessions, patients have experienced decreased numbers of postoperative delirious episodes [17].

Aside from the clinical aftermath of advanced cancer, the cancer diagnosis and treatment process cause many ramifications on the patient's social and emotional well-being. Cancer patients often deal with a range of negative emotions induced by the diagnosis, prognosis, and treatment process.The cancer experience is holistic, personal, and complex [18] and as described in [19], "has radical consequences and is an existential challenge to the patient and their family".

These psychological ramifications are prevalent in palliative care, which aims to provide comfort and pain relief and improve quality of life for patients with cancer at advanced stages. These patients often experience symptoms of suffering "especially when there is impending loss, increased dependency, and diminution of participation in life activities" [18]. Without clinically affecting the disease itself, music therapy in combination with neurofeedback therapy could show improvements in the patient's mood and emotional well-being, and can improve how the patient copes with the disease and its ramifications [19] [20] [21][22].

Chapter 2

Materials and Methods

The session configuration used in this study strays from the textbook musical neurofeedback studies such as the one described in [4]. In this particular study, the neurofeedback loop is somewhat incomplete, since the patients were not informed that the music would be played based on their EEG signals, and they were not told to try to control the musical parameters. Moreover, the arousal and valence levels were not automatically encoded into music modulation, instead, the music was played live, with a music therapist playing the acoustic guitar in each session. These derivations from the 'traditional' musical neurofeedback setup were established in preliminary discussions between the medical and musical therapy faculties at Centre Forum hospital and the MTG research team.

To reduce variability in the data, it was decided that eligible patients would be patients with advanced cancer residing in palliative care, who had an understanding of Spanish or Catalan. Moreover, the patients could not have any cognitive or hearing impairment [10]. Comparison of the results obtained from these two groups will answer the following research question: will adding real-time feedback of the patient's emotional state improve the effectiveness of a music therapy session? Our hypothesis is: yes, in designing and implementing a neurofeedback system, the music therapist can play music based on the patient's live emotional state as decoded from EEG data, which will have more effective results in improving the patient's perceived and recorded well-being.

The following section will describe the materials used in this study: starting with the theory behind the music used for the sessions, then going into each piece of equipment and software program used for the EEG measurements, recordings, and data processing.

2.1 Materials

2.1.1 Patient Participants

The sessions and trials were conducted at the Palliative Care Unit (PCU), Oncology Service, Parc de Salut Mar in Barcelona. The participants in the study were all residing in the PCU, with ages ranging from 65 to 87 years old, with an average age of 74 years old. By chance, all patients that participated in this study were male.

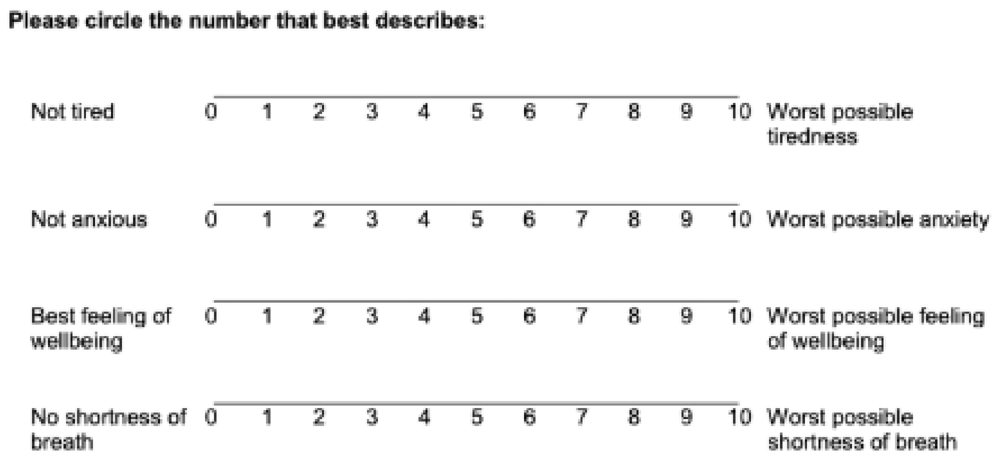
2.1.2 Participant Questionnaires

To supplement the EEG data that is collected in each session, information was also collected from the patients in the form of a questionnaire.

The questionnaire begins with questions about the patient's general information: age, diagnosis, gender, marital status, etc., which is filled out by the music therapists before meeting with the patient. Next, there are questions asking the patient to rate their tiredness, breathing difficulty, anxiety, and general well-being on a quantitative scale. These questions were referenced from the Edmonton Symptom Assessment Scale (ESAS) [23], often used in palliative care, as shown in Figure 5. To be able to assess and compare the effectiveness of music therapy on patients of different musical backgrounds, the questionnaire also includes a few questions about the patient's relationship with music, as shown in Table 1.

Table 1: Questionnaire concerning the patient's musical history.

Musical History Questions
Do you play an instrument? If so, which one(s)?
How long have you been playing? How often do you play?
Have you played the instrument recently?
Do you listen to music often?
How many hours a week did you listen to music before the diagnosis? And now?



Please circle the number that best describes:

Not tired	0	1	2	3	4	5	6	7	8	9	10	Worst possible tiredness
Not anxious	0	1	2	3	4	5	6	7	8	9	10	Worst possible anxiety
Best feeling of wellbeing	0	1	2	3	4	5	6	7	8	9	10	Worst possible feeling of wellbeing
No shortness of breath	0	1	2	3	4	5	6	7	8	9	10	Worst possible shortness of breath

Figure 5: ESAS-based questions about patient's current state.

2.1.3 Music Materials

The music used for this study consists of a simple chord progression played live by a music therapist on a classical guitar. This chord progression was established prior to the first session, in agreement between the music therapists involved. To decrease the variability between sessions and patients, the exact same chord progression and technique was used across all sessions. During the session, the patient's live arousal level was displayed on a graph on a screen facing the music therapist, who in turn modulated the volume, tempo, and melodic ornamentation of the chord progression according to the arousal value.

Since the overall goal of these sessions was relaxation, the base chord progression was played in 3/4 time, a ternary time signature often used in lullabies because of their contention effect [24]. The chords were played softly by plucking the guitar strings in ascending, then descending order, never strummed. The chord progression itself consisted of a continuous swap between the tonic and dominant chords of the chosen key.

When the patient's arousal levels declined from the subjective 'base' value, the chords were played with lower volume and the strings were plucked with decreasing tempo. Contrarily, when the arousal levels increased, the chords were plucked quicker and at a higher volume. If arousal increased further, a third - or sometimes, fourth - chord was added to the progression, along with melodic ornamentation between the chords. The idea was to make the music sound more and more intense as the patient's arousal levels were high, and more calm when arousal levels were low. This creates an overall entrainment effect; not necessarily synchronizing to an external rhythm, but rather synchronizing the intensity of the music with the level of the patient's emotional arousal.

The initial idea was to also incorporate valence into the entrainment, where the patient's emotional valence would correspond to the tonality of the music. For example, a shift from a negative valence value to a positive one would correspond to a minor-to-major key change in the music. However, valence was not used for the live entrainment and neurofeedback for this study, since technical malfunctions and signal loss with the EEG device caused the live valence calculations to be erroneous (more information on these limitations can be found in Section 2.2.4 of this report).

During each session, the music therapist also plays two or three songs of the patient's choosing, before the entrainment session takes place. These songs were entirely subjective and chosen by the patient, as the objective was to make the patient feel comfortable in the setting of a neurophysiological study. Playing songs familiar to the patient is a way to offset any discomfort caused by the study itself.

2.1.4 Muse EEG Headband

The original intention for this study was to use the Emotiv Epoc 16-sensor EEG device for all sessions. This device uses wet electrodes (i.e.: electrodes under a sponge wet with contact lens solution), and requires extensive setup and calibration time for each use. To facilitate the setup during sessions and decrease patient discomfort, the Muse headband was used for this study. The Muse, shown in Figure 6, is a commercially available EEG sensing headband available for purchase for 219 EUR [12]. The commercial intention for this device is to aid in self-guided meditation, where the user would monitor their mental state on an accompanying mobile application. This application uses principles of neurofeedback and advanced signal processing to give the user a real-time sonic interpretation of their brainwaves. The user is intended to use the real-time feedback to stay focused and motivated during meditation sessions. Despite its commercialization and low cost, using this device does not compromise the quality or reliability of its measurements, as numerous studies have compared it to professional-grade EEG devices to conclude that it is capable of accurate measurements [25].

Figure 6: Muse 2014 Headband. [25]

The Muse 2014 has seven dry EEG electrodes: three reference sensors (located at Fpz), 2 sensors on the forehead (AF7 and AF8), and 2 behind the ears (TP9 and TP10). Figure 7 shows the Muse sensor locations by 10-20 International Standards.

The Muse headband has adjustable ear pieces, allowing for a custom fit on differ-

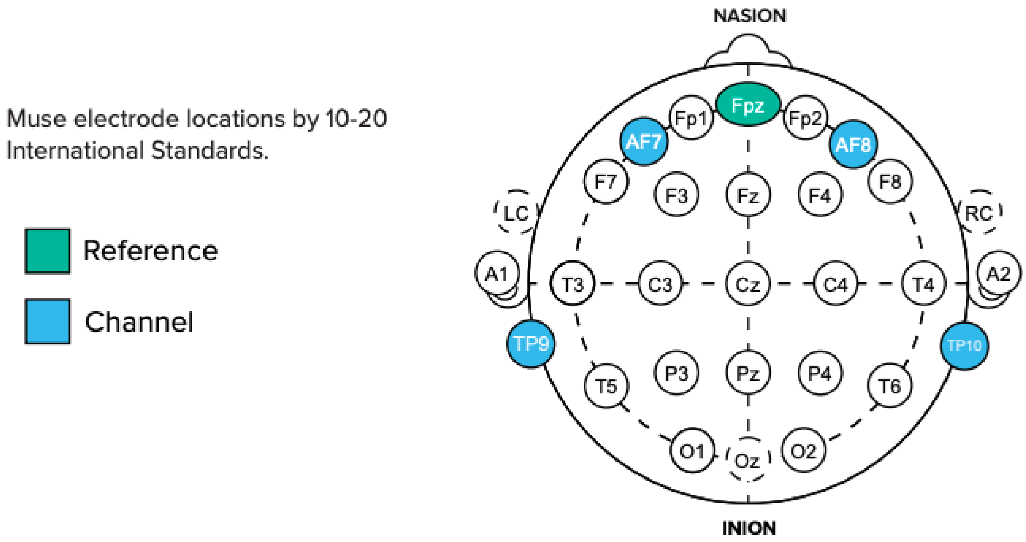


Figure 7: Muse electrode locations. [25]

ent users. However, since the band containing the electrodes does not retract or expand, the position of the electrodes on each user's forehead may differ [25]. The electrode positions on this band described in Figure 7 are based on an average-sized adult head. Displacements in the AF7 and AF8 electrode positions can be calculated and compensated for using the distance between the electrodes and the user's head circumference, however these compensations were considered negligible and not performed for patients of this study.

Newer versions of the Muse headband incorporate pulse oximetry breath and heart sensors to the signal, creating an all-encompassing biofeedback loop, however, the Muse 2014 relies strictly on EEG data. If extraneous sensors are to be added, it can be done through the headband's two USB ports.

The Muse suppliers provide support for developers that wish to create their own software or applications using the Muse headband for data extraction. There are several Software Development Kits (SDKs) available for signal processing support to aid in analyzing the raw EEG from the Muse. Muse also offers data streaming for pre-processed data. The available signals from the Muse 2014 headband are: raw EEG signals, raw accelerometer data, raw FFT coefficients, relative and absolute band powers for Alpha, Beta, Delta, Theta, and Gamma waves, and blink and jaw clench detection. [26] EEG signals are oversampled, then downsampled to yield a selectable output sampling rate from 220 Hz to 500 Hz, with 2uV (RMS) noise [25]. The absolute frequency bandpower data streams are calculated and sent ten times per second, or at 10 Hertz.

For Windows operating systems, the Muse SDK contains a program called Muse Direct, which acts as a driver, receiving the data from the headband over Bluetooth and sends it out as Open Sound Control (OSC) messages over serial User Datagram Protocol (UDP) or Transmission Control Protocol (TCP) ports to the subsequent processing programs to be used. Muse Direct also displays the current battery life of the Muse, as well as the connectivity for all seven of the headband's sensors. Figure 8 shows a screenshot of the Muse Direct program.

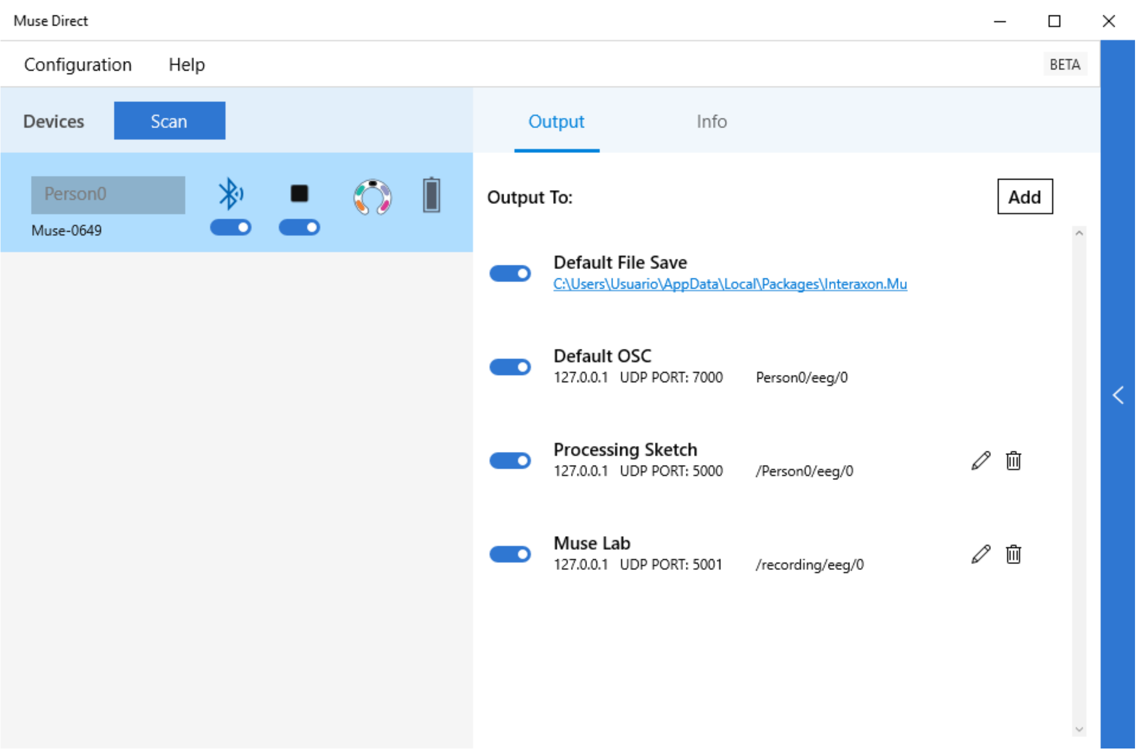


Figure 8: Screenshot of the Muse Direct program showing the connected Muse 2014 headband and connected serial ports.

MuseLab is the program used for visualization of the received data streams. It receives the streams from the serial port specified in Muse Direct and allows the user to create a graphical interface showing the stream of real-time data. There are many features that allow for manipulation of the graphs, such as the addition of markers and some signal processing features. Figure 9 shows a screenshot of MuseLab's visualizer showing a patient's live alpha absolute bandpower.

MuseLab also allows the user to record the data stream, all the while displaying a chronometer to assist in log-keeping and corroborated timestamps. MuseLab also allows the user to save the data into a .muse file. Muse files are organized by data type, such that all raw EEG data will be clustered together, all gyroscope data will be clustered together, etc. However, there is no correlation between the order of the data sequences, and they are not organized by time. Muse files are thus not an ideal format for the purpose of post-processing the recordings and calculating arousal and valence values at specific timestamps.

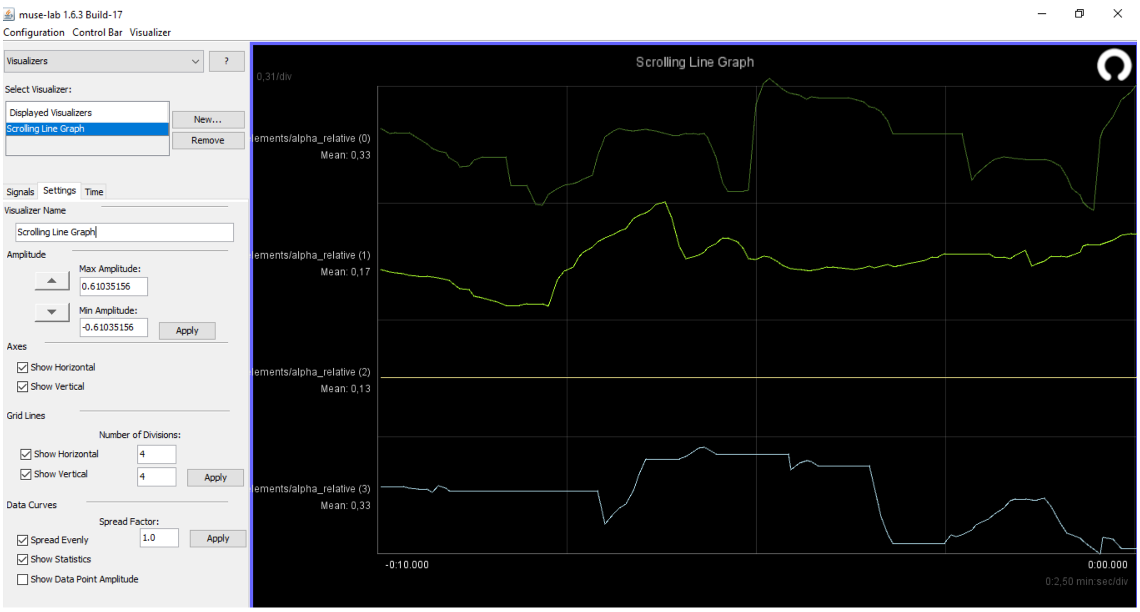


Figure 9: Screenshot of the MuseLab data visualizer showing live scrolling alpha absolute bandpower data.

Muse Player is an open-source toolbox, accessed through the computer's command prompt, which can re-route, record, play back, and convert Muse raw data streams and files. We use this utility to convert the muse files into CSV files, which are organized by timestamp and can be opened in Microsoft Excel for further analysis.

Table 2: Supported file formats for Muse Player conversions. [27]

Supported Inputs	**Supported Outputs**
OSC network stream	OSC network stream
Muse file format v1	Muse file format v2
Muse file format v2	.mat (MATLAB)
.txt (oscreplay)	.txt (oscreplay)
	.csv
	Print to screen

These recordings are analyzed according to the logs kept during the session, in order to note any differences in emotional state at specific or notable times during the session. For example, it would be important to note if there an increase in arousal was due to a cell phone ringing rather than a response to the music.

2.1.5 Processing Interface

Since MuseLab is only able to display graphs for data that is directly transmitted from the Muse, a new custom graphical interface was required, where arousal and valence values could be calculated in real time from the incoming alpha absolute bandpower data streams and displayed on their own graph. For this purpose, we used Processing: a free and open-source software sketchbook development tool, "geared towards creating visual and interactive media" [28]. Processing allows for the creation of user-friendly graphical interfaces as well as real-time OSC data configuration, using Java-based programming. A detailed description of the code implemented in Processing can be found in Section 2.2.2.

2.1.6 Recordings

On the Muse Lab software, we are able to create .muse file recordings with the raw measured data. For each session, .muse files are recorded, saving all possible data recorded by the Muse. However, in post-processing, only the alpha relative bandpowers are used. The muse files are converted into Comma Separated Variable

(CSV) files using the command prompt. This allows for analysis of the data in spreadsheet format on Microsoft Excel.

2.2 Methodology

2.2.1 Session Methodology

Eligible participants for the study are first referred to the music therapists by the medical staff, and a brief synopsis of the patient's condition is given to determine whether the patient would benefit more from a relaxing or activating entrainment session.

The first step in the process is to propose the study to an eligible patient; explaining the principles of neurofeedback therapy and how an entrainment session could benefit them. If the patient consents to participating in the study, the first step is to pose a questionnaire about the patient's well-being and current state. The exact questions asked are as described in Section 2.1.2. At the end, the patient also reads a few paragraphs describing the experiment and the data collected from it, which they then sign and consent to, as a formality for the hospital centre.

Before each music therapy session begins, an initial state of mental activity is recorded for approximately 2 minutes, to record, and later, calculate initial levels in arousal and valence. After this, the patient hears at least one song according to his or her musical preference, followed by an entrainment session.

During this session, the patient is encouraged to close their eyes and focus on the music being played. As they listen to the music, their live arousal and valence values are displayed on a screen to the music therapist, who will adapt the music accordingly, creating a feedback system that will have the music reflect the emotional state of the patient. A log of notable reactions and events is also kept during the session, to note qualitative effects of the neurofeedback music therapy (such as the patient falling asleep, smiling, talking, etc.).

At the end of the session, a 'final' state of mental activity is recorded for approximately 2 minutes, to establish post-therapy levels of arousal and valence. Finally, the ESAS questions are posed once again at the end of the session, in order to compare the patient's self-perception of their mood before and after the session, as well as their measured values.

The established procedure of these sessions has largely been influenced by the notion that the patient should feel at ease during the whole session, so as to minimize stress and anxiety. Events are largely organized so that during the time needed to set up the programs and configure the headband, one of the music therapists is chatting with the patient or playing a song that they have requested.

2.2.2 Implementation of a Live Arousal Graph

During each session, the music therapist required an interface that would clearly show the live calculated arousal level of the patient, in order to play accordingly to their emotional state. After several discussions with the music therapists on what they would like to see on the user interface, the graph was implemented on Processing.

The first step in the Processing code is to set up a function that will read the incoming OSC data stream, shown in Figure 10. In this function, we set the frame rate to 10 Hertz, to match the OSC data stream rate, and the program reads the messages from port 5000 of the computer's specified IP address. After this function, the data can be parsed using the labels defined by the Muse protocol (e.g.: /Person0/elements/alpha_absolute to access the alpha absolute data stream).

Next, the OSC messages are forwarded to a second function, where the data will be parsed and the calculations and signal processing are implemented. Figures 11 and 12 show the complete function, which starts by setting up all the necessary variables, then implementing the equations to calculate arousal.

The emotional classifiers of arousal and valence can be calculated using the following equations:

$$Arousal = 1/(\alpha AF7 + \alpha AF8)$$

```
void setup() {
  size(500,200);
  frameRate(10);
  /* start oscP5, listening for incoming messages at port 5000 */
  oscP5 = new OscP5(this,5000);

  /* myRemoteLocation is a NetAddress. a NetAddress takes 2 parameters,
   * an ip address and a port number. myRemoteLocation is used as parameter in
   * oscP5.send() when sending osc packets to another computer, device,
   * application. usage see below. for testing purposes the listening port
   * and the port of the remote location address are the same, hence you will
   * send messages back to this sketch.
   */
  myRemoteLocation = new NetAddress("127.0.0.1", 5000);

}
```

Figure 10: Function of Processing code that sets up the OSC port and reads the incoming data stream.

$$Valence = \alpha AF8 - \alpha AF7$$

```
/* incoming osc message are forwarded to the oscEvent method. */
void oscEvent(OscMessage theOscMessage) {

  if(theOscMessage.checkAddrPattern("/Person0/elements/alpha_absolute")==true) {

    // Get the value from sensors on the Muse, 0 to 3 goes from left to right
    //   on the headband.
    // Change accordingly depending on the signal strength from the Muse.

    double alpha0 = theOscMessage.get(0).doubleValue();
    double alpha1 = theOscMessage.get(1).doubleValue();
    double alpha2 = theOscMessage.get(2).doubleValue();
    double alpha3 = theOscMessage.get(3).doubleValue();

    // We are using values from sensor 1, we print the incoming alpha-relative
    //   values to test the OSC signal.

    // Convert incoming OSC double  messages to float
    float value_out0 = (float)alpha0;
    float value_out1 = (float)alpha1;
    float value_out2 = (float)alpha2;
    float value_out3 = (float)alpha3;
```

Figure 11: Snippet of Processing code that sets up the necessary variables to parse through the alpha absolute bandpowers for each of the four Muse electrodes. As a formality for subsequent computations, the double messages from the OSC stream are converted to floats.

The bandpower data is received at 10 Hertz, and in practice during sessions, the streamed values tended to be erratic between samples; jumping around by wide margins due to noise or movement on the sensors. To create a more stable, smoothed-out reading, windowing was applied in order to calculate a moving average over 4 seconds of signal (40 samples). This allowed for a more continuous line and for the interface to display a longer history of data, such that the music therapist playing the feedback is able to compare current values to past values and change the music accordingly. The moving average is computed in a separate function, 'MovingAverage', shown in Figure 13. With every new value that is streamed, the function will shift by one value, such that the function will not change erratically.

```
    /* initialize an object to contain alpha data for an incremental 4-second window */

    MovingAverage m = new MovingAverage(100);
    float arousal_avg = m.next(value_out0 + value_out1);

    float arousal = 1/arousal_avg;


    // Map the values to the range of the sketch size, so that it is visible
    map(arousal, 0, 10, 0, 12*height);

    // Calculate the logarithm of the arousal value, to amplify small changes
    //  in lower arousal values and decrease the drastic changes in spikes.
    //  We can try computing 20*log(arousal) to smooth out the amplitude of the signal.
    //  This will improve the live entrainment for the music therapist, since changes
    //  in arousal will be easier to read.
    float log_arousal = 20*log(arousal);
    println(" values: " +log_arousal);

    // For an x-y plane showing arousal on the y-axis and valence on the x-axis:
    //    Subsitute "width" in the following line with "0.5*width + valence"
    Points P = new Points(width, height-log_arousal);

    data.add(P);

    return;
  }
}
```

Figure 12: Snippet of Processing code where arousal is calculated from the filtered alpha bandpowers. The filtering is done in another function, "MovingAverage".

Figure 14 shows the function that deals with setting up the pixel size, background, line stroke, and plotting algorithm for the arousal graph. In order to improve the visualization of the brainwave fluctuations, the arousal and valence were multiplied to scale with the computer screen, and displayed on a logarithmic scale, such that small differences between low values were amplified, and large noisy spikes were

```
class MovingAverage {
  private Queue<Float> queue;
  private int maxSize;
  private float sum;

  /** Initialize your data structure here **/
  public MovingAverage(int size) {
    queue = new LinkedList<Float>();
    maxSize = size;
    sum = 0.0;
  }

  public float next(float val) {

    // Whenever a new value comes in, remove the oldest element
    //   from the sum in order to add the new value.

    if(queue.size() == maxSize) {
      sum -= queue.remove();


    }
```

Figure 13: Function of Processing code where the moving average over four seconds is computed.

scaled down. In the analysis of the recorded data, this scaling was not applied, and was purely to improve the feedback system and to make it easier for the music therapist to play the live changes. Figure 15 shows the resulting scrolling line graph depicting arousal, as well as the window beneath it displaying the numerical value of each sample as the data is streamed.

In theory, the arousal-valence goal state for each session differed, depending on the patient's needs and the doctor's recommendations. Some patients are lethargic or depressed and benefit from activation, others are delirious or anxious and require relaxation. In practice, every patient encountered for this study shared the common goal of relaxation.

```
void draw() {

  background(-1);
  frameRate(10);
  noFill();
  strokeWeight(4);
  stroke(0);
  beginShape();
  for (int i=0; i<data.size(); i++) {
    Points P = (Points)data.get(i);

    vertex(P.x, P.y-100);
    if (P.x<0)data.remove(i);
    P.x--;
  }
  endShape();
}
```

Figure 14: Function of the Processing code that sets up the visual interface.

2.2.3 Configuration of the Materials

There are two orders of configuration for the programs described in Section 2.1.4 of this report. First, for the purpose of the neurofeedback arousal and valence graph interface, the configuration sequence is as shown in Figure 16.

Next, for the purpose of visualizing raw data and recording brain activity in a session, the configuration sequence is as shown in Figure 17.

During a session at the care units, both configurations are executed, such that sessions can use live feedback and be recorded for post-processing and analysis.

The goal sample size for this study was to hold 20 sessions of music therapy total: 10 sessions using the visual interface for neurofeedback (experimental group) as in Figure 16, and 10 sessions with only 'traditional' music therapy, while recording the EEG signals for post-processing (control group). Sessions last 20 minutes on

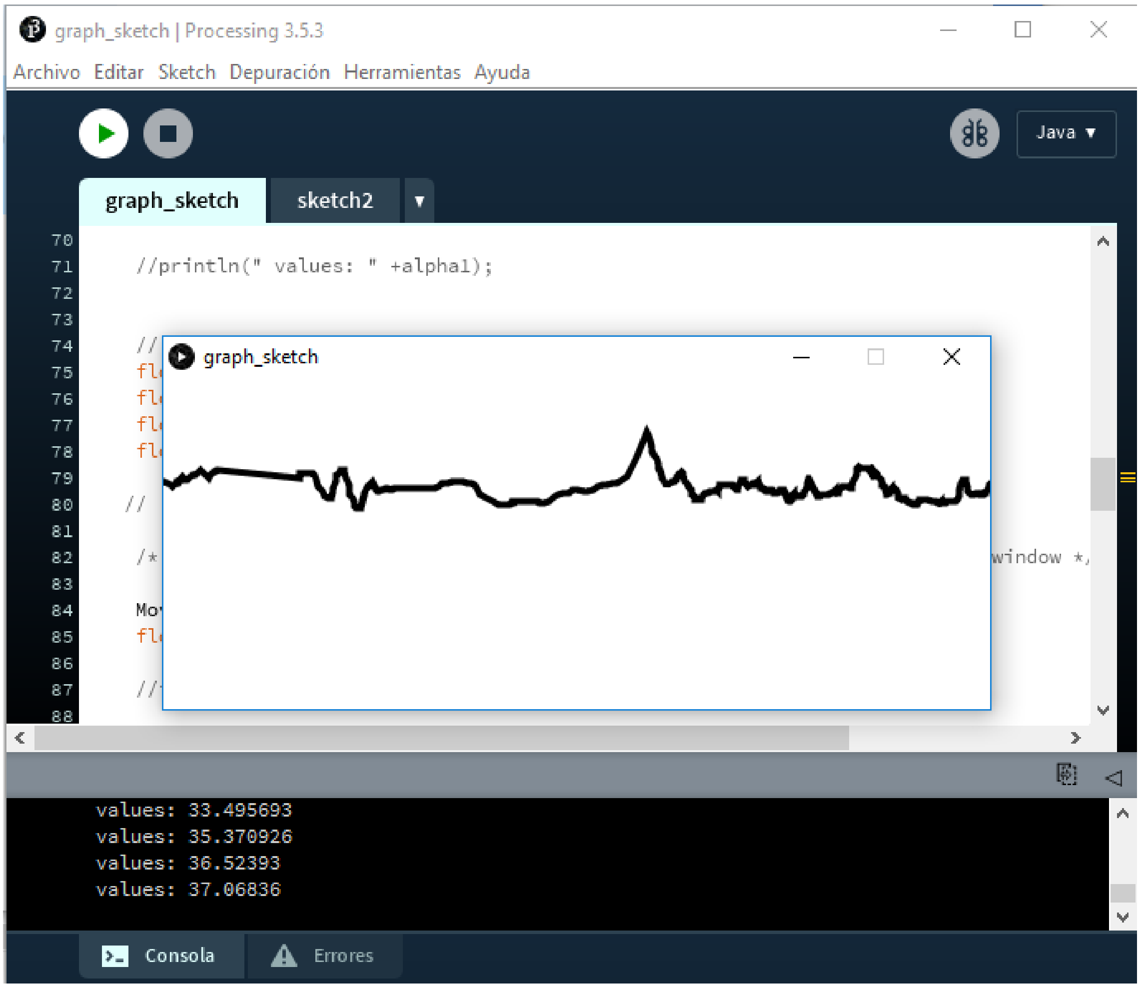


Figure 15: Screenshot of the scrolling line graph showing a patient's live arousal values.

average. The idea is to compare the effects of neurofeedback and entrainment to the effects of traditional music therapy and identify and trends of improvement or deterioration.

2.2.4 Limitations

In the four months of sessions and trials, many limitations, both technical and circumstantial, have impeded the progress of this study.

The main technical limitation concerns the Muse 2014 itself. The configuration and chain of programs described in the previous section only allows for compatibility with the 2014 model of the Muse headband. The Muse 2016 and Muse 2 both had

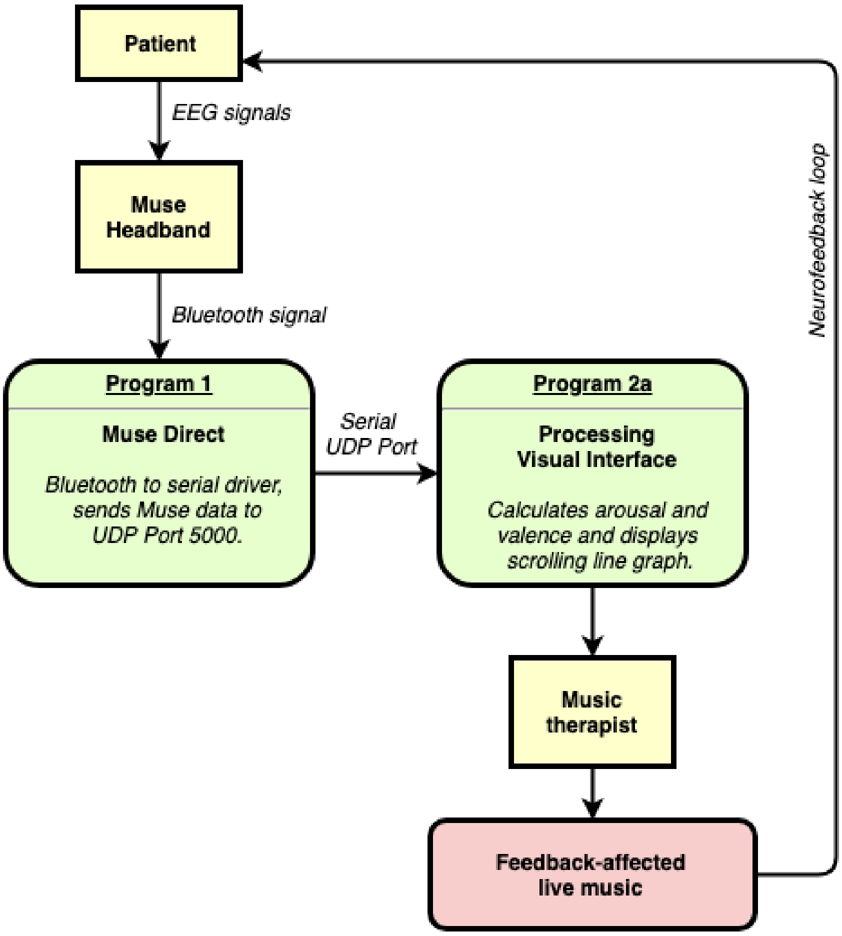


Figure 16: This chart shows the data flow sequence for the neurofeedback session.

connectivity problems with Windows and Mac operating systems and could not be detected by the Muse Direct driver, and thus could not be used as supporting devices for this study. This limited number of available devices to just one EEG headband.

In addition to this, the Muse 2014 device used has a battery life that lasts just under 40 minutes for continuous use, per full charge. This limits us to one music therapy session per charge, including the time it takes to setup the programs, and calibrate. Moreover, with its intentional use as a meditation headband, it is recommended that the wearer stay sitting upright and immobile for two minutes, to allow the headband to calibrate properly and to obtain a good signal across all sensors on the headband. Due to the medical condition of the patients, many are unable to stay sitting upright or still, and often shift with discomfort or natural movement throughout a session. This affects the sensor connectivity, and often, the Muse will lose signal in one or

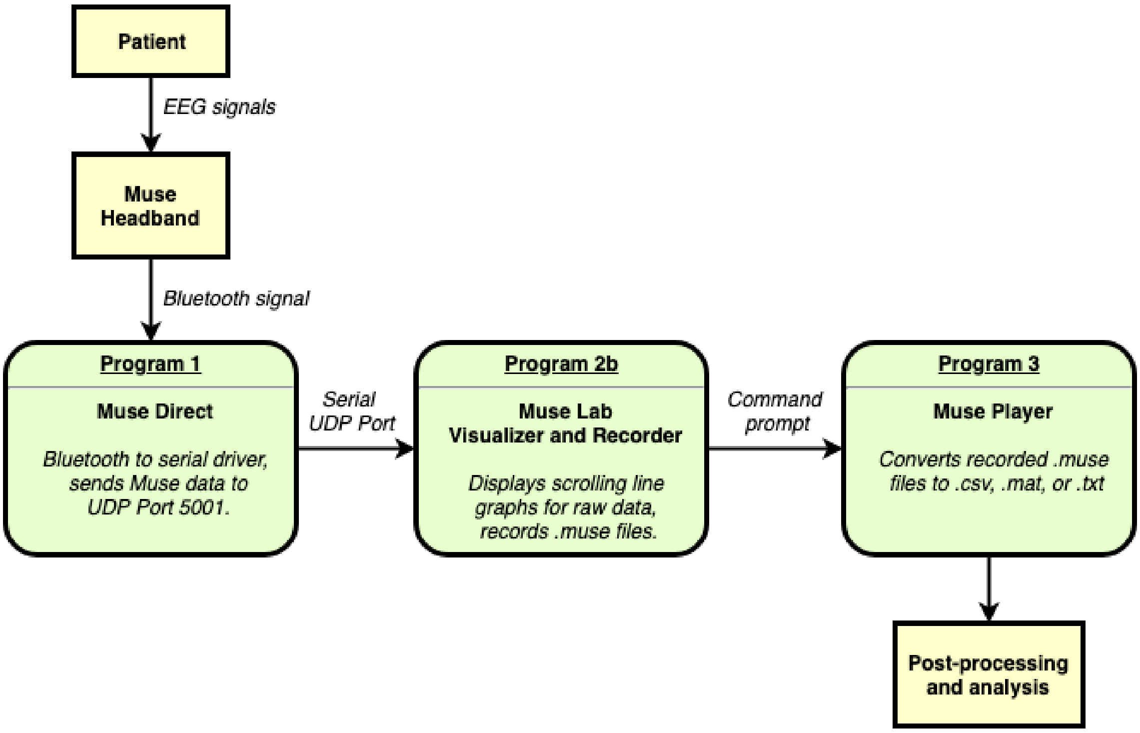


Figure 17: This chart shows the data flow sequence for the recording and post-processing and analysis of EEG activity.

more sensors during a session.

Even during the calibration and the recording of the initial state, the Muse often loses signal due to hair obstructing the sensors, and sometimes it simply does not fit well on differently-shaped heads. Any other sensors or objects obstructing the patient's forehead and behind-the-ear area, such as oxygen tubes, glasses, or bandages, also affects the signal of the Muse electrodes. These sudden losses of connectivity affect the streaming data unpredictably within sessions. Often, one sensor on the right or left does not have good contact due to head shape, which affects the readings, especially for valence, which is calculated as the difference between the brainwaves from the left and right lobes of the brain. It is for this reason that a live valence graph was not displayed during the entrainment sessions. Since the first and foremost objective of this study is to improve the patient's overall state and quality of life, it is paramount that they are comfortable during the study, so there are limitations to the time we can spend troubleshooting or adjusting during a session. There are ethical boundaries to consider, especially with patients at the end-of-life stage in palliative care.

There were also limitations concerning patient eligibility for participation in this study. The technical issues aforementioned narrowed the available sample size (i.e.: if an otherwise perfect candidate had a head bandage, they would not be able to participate). Furthermore, due to the need for pre- and post-session assessments of the patient's well-being with the questionnaires, patients also had to be conscious and able to communicate answers.

Finally, due to the nature of palliative care, patients often do not spend extended periods of time residing in the PCU, which limited the study to single sessions for each individual patient. Although repeated weekly sessions with each patient would be the ideal setup to monitor therapy-related improvements over time, this approach was not possible in the allotted time for this study.

Due to all these limitations, the target goal of 20 patients has not been reached, but the data collected from the sessions will be analyzed nonetheless. The results obtained will be described in the following section.

Chapter 3

Results and Discussion

Due to the limitations described in Section 2.2.4, we have only been able to collect complete sets of data from 5 patients in the experimental group and 2 patients for the control group between April and July 2019.

There are two ways that the results can be analyzed: contextually on a case-by-case basis, or collectively by comparing the results of the two groups as entities. Because of the small sample size and the subjective nature of palliative care, it is important for this study to analyze each patient's session individually. This way, we can determine whether the session was successful based on the patient's subjective needs with respect to the qualitative data collected. For each session, the patient expresses verbal feedback towards the entrainment session and the music therapy session as a whole. All patients to date have expressed that the overall session was not uncomfortable or aggravating, and that the session did help them relax.

Evidently, we will also perform a quantitative analysis of the recorded EEG data. We can create charts showing average arousal and valence values, respectively, over the course of individual events (i.e.: first song, talking, entrainment session, etc.). This is done by converting the recorded Muse files into CSV files, then using Microsoft Excel to compute average values over selected event periods in the session.

Table 3: Average Differences in Arousal and Valence

Emotion Classifier	Control Group	Experimental Group
Arousal	0.7465	-0.1068
Valence	0.0426	-0.0514

3.1 Comparative Quantitative Analysis between Groups

The first mode of analysis consists of analyzing the results of the experimental group with respect to the results of the control group. This is a way to generalize the results from the session, and achieve an approximate answer to the research question: did adding entrainment to the music therapy session improve results?

The recorded EEG data (in CSV file format) was used to compute the average arousal and valence levels at the beginning and end of each session. From the average levels of each session, the average differences in arousal and valence for the entire experimental and control group can be computed, respectively.

The overall results are shown in Table 3. It is important to note that these averages are computed for each group respectively, but that the groups have different sample sizes. There are only two sessions in the control group, and five in the experimental group. Despite this, it can be shown that the experimental group, on average, experienced a decrease in arousal over the course of their sessions. This is an improved result over that of the control group, since the therapeutic objective of the sessions for each and every one of these patients was relaxation. A decrease in measured arousal denotes a successful relaxation session.

As for valence, both groups showed very small overall differences between initial and final measured valence levels. However, the control group did show an overall valence increase, and the experimental group showed a decrease. The goal for any kind of therapeutic session is to achieve an increase in valence (i.e.: achieve positive emotions rather than negative).

We can further analyze the results by looking at the effectiveness between different demographics in the sample size. In doing this, we can identify any trends such as

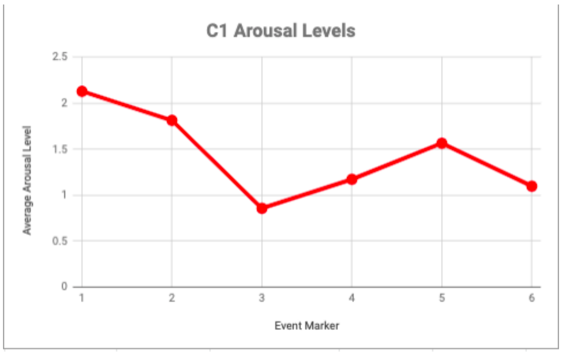


Figure 18: Arousal levels for patient C1. 1=initial, 2=first song, 3=new section in song, 4=talking, 5=second song, 6=final

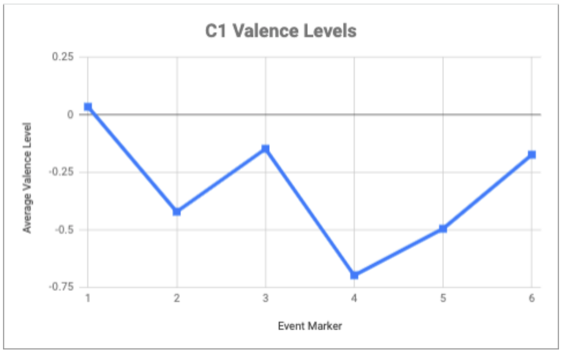


Figure 19: Valence levels for patient C1. 1=initial, 2=first song, 3=new section in song, 4=talking, 5=second song, 6=final

higher effectiveness in one gender, or higher effectiveness on patients with a stronger musical background than others. However, by chance, all seven of the recorded sessions involved male patients, so we are unable to compare results between genders. In all, there were no noticeable improvements in the results from patients that played an instrument or had a stronger musical background.

3.2 Contextual Analysis

3.2.1 Control Group Results

Patient C1 was the first patient of the control group to participate in this study. Figures 18 and 19 show the average arousal and valence values calculated during a session from the recorded data, with markers showing important moments (e.g.: specific songs, entrainment session, etc.).

We can also assess Patient C1's session using the qualitative data collected during the session and from the questionnaires. Table 4 shows the pre- and post- session results from Patient C1's ESAS questionnaire. It shows a decrease in perceived anxiety after the session had taken place. The patient also expressed that they felt more relaxed at the end of the session.

Patient C2 was the second patient in the control group to participate in this study. The average recorded arousal levels shown in Figure 20 shows a slight decrease in

Table 4: Patient C1 ESAS Questionnaire Answers

ESAS Question	Before	After
Tiredness	8	8
Difficulty breathing	7	7
Anxiety	3	2
Well-being	1	1

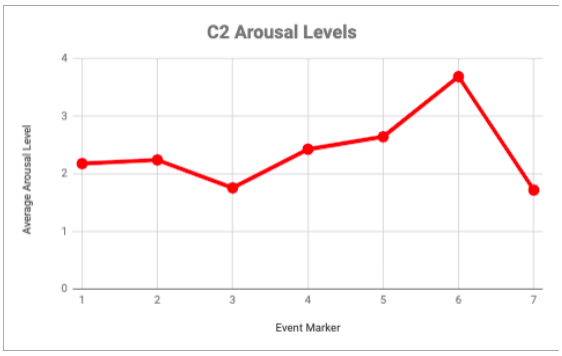


Figure 20: Arousal levels for patient C1. 1=initial, 2=talking, 3= first song, 4=talking, 5=second song, 6=final

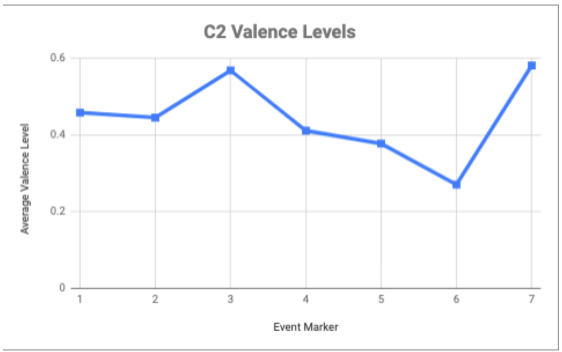


Figure 21: Valence levels for patient C1. 1=initial, 2=talking, 3= first song, 4=talking, 5=second song, 6=final

arousal during the first song at marker 3 - which, in fact, was a very slow and soothing song. The second song was a more upbeat havanera, which in turn shows an increase in arousal. The final arousal value is slightly lower than the initial.

As for valence, Figure 21 shows that during the first song, measured valence became more positive, however decreased for the second song. Overall, the resulting valence was significantly higher than the initial value, suggesting a positive impact from the session.

Patient C2's questionnaire ratings show positive results for the session: with a decrease in anxiety and an increase in overall well-being.

Table 5: Patient C2 ESAS Questionnaire Answers

ESAS Question	Before	After
Tiredness	7	7
Difficulty breathing	2	2
Anxiety	4	2
Well-being	2	3

Figure 22: Arousal levels for patient X1. 1=beginning, 2=first song, 3=talking, 4=second song, 5=talking, 6=explaining study, 7=entrainment session, 8=final

Figure 23: Valence levels for patient X1. 1=beginning, 2=first song, 3=talking, 4=second song, 5=talking, 6=explaining study, 7=entrainment session, 8=final

Table 6: Patient X1 ESAS Questionnaire Answers

ESAS Question	Before	After
Tiredness	5	5
Difficulty breathing	1	1
Anxiety	4	2
Well-being	5	6

3.2.2 Experimental Group Results

Patient X1 was the first patient of the experimental group to participate in this study. In his session, two songs of the patient's choosing were played, followed by a 7-minute entrainment session. From Figures 22 and 23, it can be seen that there is a spike in both arousal and valence around marker number 4, which marked the second song played. This is to be expected, as the patient had requested to hear his favourite song, and was singing along to it. Other than these spikes, there were no other noticeable changes in arousal, and the final arousal was slightly higher than the initial state. The average valence levels were higher at the end of the session, suggesting a positive impact on the patient.

Patient X1's questionnaire results can also be assessed in this anlysis. Table 8 shows that there was a decrease in the patient's self-perceived anxiety levels, and an increase in overall well-being.

Patient X3 was the third patient of the experimental group. His sessions consisted

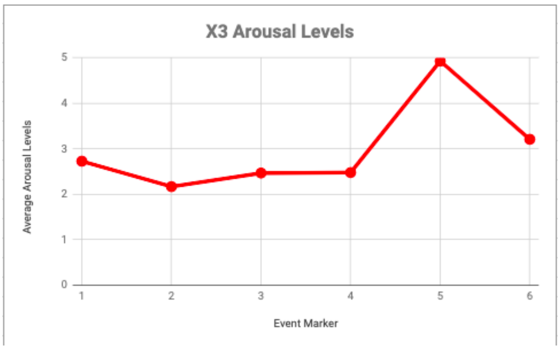


Figure 24: Arousal levels for patient X3. 1=beginning, 2=first song, 3=talking, 4=second song, 5=talking, 6=explaining study, 7=entrainment session, 8=final

Figure 25: Valence levels for patient X3. 1=beginning, 2=first song, 3=talking, 4=entrainment session, 5=melody added, 6=final

Table 7: Patient X3 ESAS Questionnaire Answers

ESAS Question	Before	After
Tiredness	8	6
Difficulty breathing	9	7
Anxiety	5	2
Well-being	5	5

of one song of his choosing, followed by a 9-minute entrainment session. Figures 18 and 19 show the resulting average arousal and valence graphs throughout the session. It can be seen that there is a spike in arousal around marker 5 (i.e.: when a melody was added to the chord progression in the entrainment session). Although the arousal levels do not show a decrease - or successful relaxation - the valence graph shows a slow and steady increase in valence as the session progressed.

Patient X3's questionnaire answers also show positive results for the session. Table 7 shows a decrease in tiredness, breathing difficulty, and anxiety.

The graphs and tables showing the results from the other three experimental group sessions can be found in the Appendix of this report.

Chapter 4

Conclusions and Future Work

The live arousal graph created on Processing proved useful for the interpretation of the patient's emotional state. The music therapist was able to use the graph - in tandem with visual cues from the patient's breathing pattern - to determine whether to intensify the music to reflect arousal.

The overall average arousal and valence levels for before and after the sessions showed that patients in the experimental group had lower arousal levels post-session than patients in the control group. These results also showed that patients in the control exhibited higher valence levels post-session than the other group.

Due to the small amount of complete sessions conducted, no strong conclusions can be drawn from the resulting data. However, based on individual patient needs, each session did show positive results, as shown through questionnaire results and verbal feedback from the patient. The first and foremost objective of each session was that the patient was comfortable and having a positive experience. This objective was met in both the control group and the experimental group, with no notable improvements in one group versus the other.

More sessions need to be conducted - at least 10 patients per study group - to draw a meaningful conclusion from the data. Also, to alleviate some of the technical limitations of this study, a newer version of the Muse device should be used, to improve the battery life and sensor connectivity. Changing the device may, in turn, alleviate some of the circumstantial limitations encountered. For instance, perhaps a device in better condition will react with more stability to movement. Ideally, a hospital-grade adhesive device maybe a better choice for a study concerned with patients that may be lying down or shifting. These solutions will decrease the criteria for patient eligibility, which will lead to a greater sample size for patient participation.

List of Figures

List of Tables

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Appendix A

Remaining Graphs for Experimental Group

Arousal and valence graphs over the course of the session for Patient X2. (Markers: 1=initial, 2=first song, 3=talking, 4= entrainment session, 5=final).

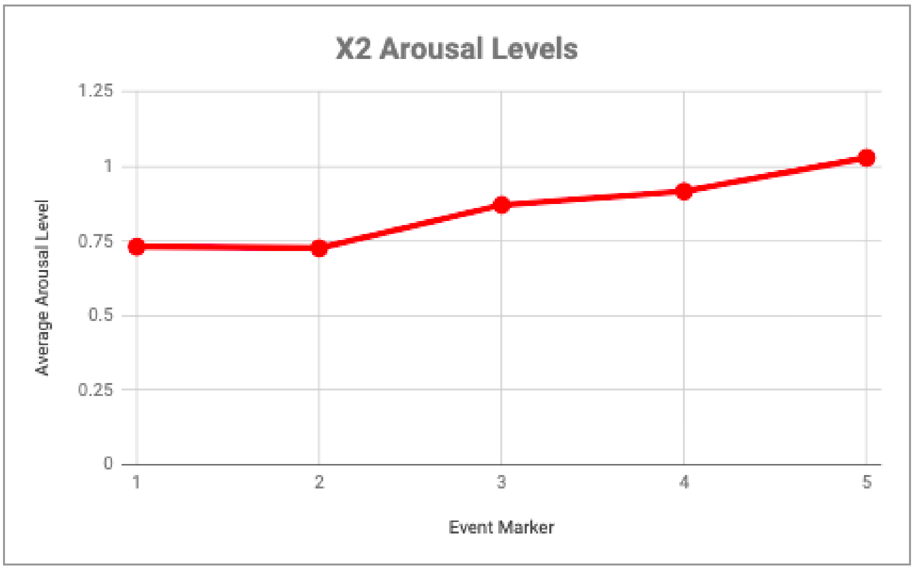

Figure 26: Arousal levels for Patient X2

Arousal and valence graphs over the course of the session for Patient X4. (Markers: 1=initial, 2=first song, 3=talking, 4= second song, 5=talking, 6=explaining study, 7=entrainment session, 8=final).

Figure 27: Valence levels for Patient X2

Table 8: Patient X2 ESAS Questionnaire Answers

ESAS Question	Before	After
Tiredness	8	8
Difficulty breathing	5	5
Anxiety	3	3
Well-being	5	5

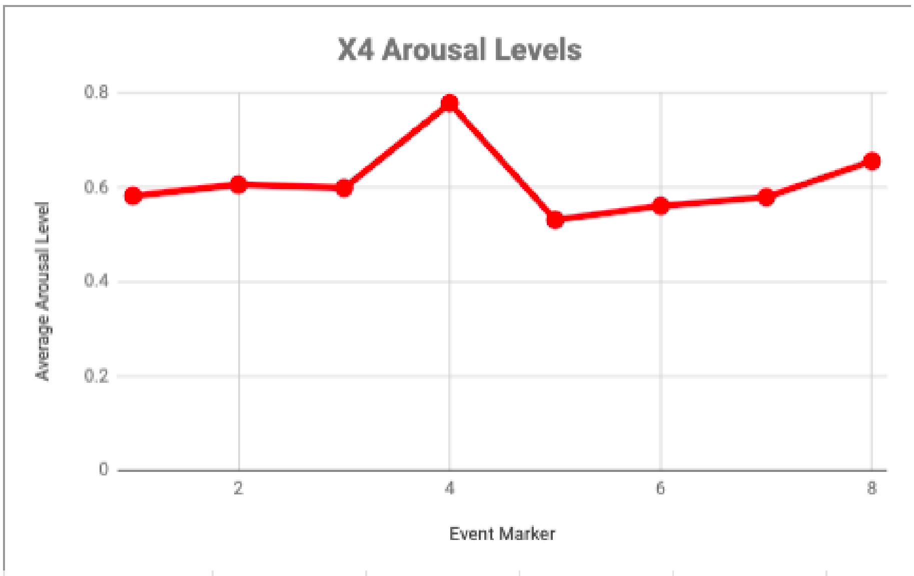

Figure 28: Arousal levels for Patient X4

Figure 29: Valence levels for Patient X4

Table 9: Patient X4 ESAS Questionnaire Answers

ESAS Question	Before	After
Tiredness	8	8
Difficulty breathing	7	7
Anxiety	3	2
Well-being	1	1

Arousal and valence graphs over the course of the session for Patient X5. (Markers: 1=initial, 2=first song, 3=talking, 4= entrainment session, 5=final).

Table 10: Patient X5 ESAS Questionnaire Answers

ESAS Question	Before	After
Tiredness	5	3
Difficulty breathing	0	7
Anxiety	7	3
Well-being	5	7

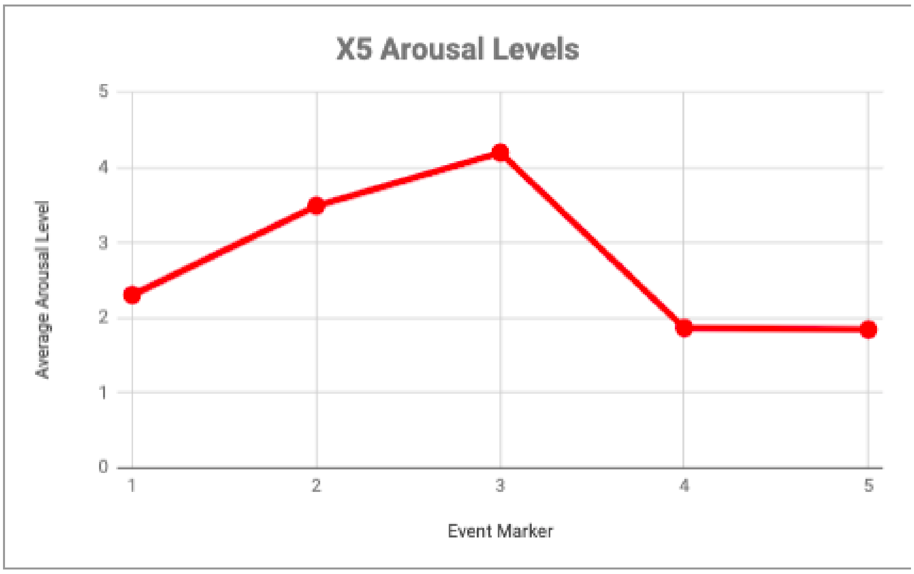

Figure 30: Arousal levels for Patient X5

Figure 31: Valence levels for Patient X5