École polytechnique de Louvain

Virtual Reality Implementation and Testing of signal detection for remote activation of guitarist's effects pedals on stage

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Abstract

Audio effects are a key mechanism for guitar players. These effects are currently activated through a footswitch disposed on a pedal on the stage or by an external sound engineer. This solution greatly limits the artist's mobility and the creative spontaneity during the concert.

The goal of this work is to develop new trigger mechanisms for the activation of these effects. This way the guitarist gains mobility and creativity freedom by triggering the effects independently through body gesture.

Three mechanisms, an electromyography (EMG) signal detection, a foot pressure sensor and an eye blink recognition, were implemented and tested during a virtual reality (VR) experiment including calibration, training and immersive mini-games.
Insights garnered from participants opinions, performance metrics, and system usability evaluations shed light on the intricate interplay between user preferences and technical efficacy.

The three mechanisms, while having each their own limitations such as setup difficulties and bulkiness, were successfully implemented. The VR environment could be developed and experienced by 4 participants.
The evaluations showed that the foot pressure detection mechanism, despite being the most similar to the classical trigger method, was not the most valued by users.

A real-life like concert stage was implemented in a VR environment to allow users to experience a real-life like scenario. In this environment, the three new trigger methods for guitar audio effects were implemented and tested. It emerged that the EMG signal detection was the most reliable solution.
This work opens new prospects for the development of musical effects triggering methods allowing for more freedom and creative spontaneity to the artist.

Keywords: Audio guitar effects, Remote activation, Virtual reality, EMG, Foot pressure sensor, eye blink recognition.

Contents

Introduction

Advancements in technology have continually reshaped the landscape of musical performance, enabling musicians to explore new realms of creative expression. One area that has witnessed significant innovation is the realm of audio effects for guitars. Traditional methods of activating these effects, often reliant on footswitches or dedicated sound engineers, are being reimagined through new technologies, with the potential to revolutionize live music performances. In this context, we delve into the realm of remote activation mechanisms for audio guitar effects, propelled by the immersive possibilities of Virtual Reality (VR) environments.

Guitar effects play a pivotal role in shaping a musician's sonic identity, enhancing their musical narratives, and captivating audiences. However, the orchestration of these effects during live performances has historically been tethered to manual footswitches, potentially constraining a performer's mobility and creative spontaneity. For accomplished artists with dedicated off-stage teams, the presence of a skilled sound engineer has been a staple, ensuring seamless effect transitions that synchronize harmoniously with the musical journey.

The emergence of VR offers an unparalleled platform for exploring the interaction between technology and musical expression. This synthetic environment not only permits the emulation of real-world scenarios but also unlocks the potential to transcend physical limitations, enabling us to dissect the nuances of each activation mechanism within an adaptable and controlled setting.

Our research encompasses a meticulous examination of various remote activation strategies, each harnessing different aspects of technology to initiate guitar effects. We delve into the utilization of Electromyography (EMG) signals, foot pressure sensors, and eye blink recognition as potential triggers, weaving together a comprehensive fabric of exploration and analysis. By dissecting the advantages and challenges inherent in each approach, we illuminate a pathway toward enhancing live musical experiences.

Through empirical experimentation, we scrutinize the performance of these mechanisms, evaluating their reliability, precision, and usability within a VR context. Furthermore, we investigate the compatibility of these solutions with the peculiarities of musical performances, considering factors such as movement, timing, and comfort for the artist.

Chapter 1

Multi-modal interaction

Among professional guitarists, it is customary to possess a selection of pedals on which lies the footswitch activating the effects, ensuring versatility in their sonic palette. Consequently, their pedalboards can comprise an impressive collection, sometimes encompassing over 20 pedals. The pedals sometimes have to be activated multiple times over the same music track.
While one of the most prevalent effects is distortion, a plethora of other pedals exist for various specific applications. Among these is the delay pedal, which introduces an echoing quality, a reverb pedal that conjures the ambiance of a spacious environment with lingering reverberations, and even more distinctive effects such as the "Wah-Wah" pedal, named after the characteristic sound it produces.
Guitarists performing on stage often find the need to activate or deactivate their pedals, enhancing or removing distinct sound effects during their play.

These effects are typically activated using a footswitch on the pedal. For seasoned professional artists who have an off-stage support team, it is customary to have a skilled sound engineer familiar with the set, poised to trigger the effects at precisely the opportune moments.

To enable the remote activation or deactivation of these effects, the first step involves detecting a trigger signal. Multiple detection methods are implemented and rigorously tested to identify the most practical approach. It is also conceivable to tailor a specific detection method to each pedal, thereby facilitating the activation of a range of distinct sound effects.

Virtual reality (VR) is an immersive technological environment that simulates a three-dimensional, computer-generated reality. It leverages a combination of visual, auditory, and sometimes haptic (touch-related) cues to create a synthetic world that users can perceive as real.
By using specialized headsets or goggles, users are able to step into this simulated environment. The orientation and position of the user's head and hands are tracked by integrated sensors to adapt the visual content displayed by the headset allowing for interactive experiences, exploration, and often manipulation of objects within this virtual world.
VR is, in this work, used to create a virtual calibration and training center for each solutions, as well as a concert stage to put the user in a real-life like scenario.

Three new triggering methods undergo comprehensive evaluation through a VR experiment. However, for the experiment's purposes, only the detection of the trigger signal holds relevance, as the VR environment inherently manages the visual and audio feedback as well as the effect switching. In real-world scenarios, once the trigger signal is detected, the information still needs to be remotely transmitted to the pedal.
This transmission can be accomplished using technologies like Bluetooth or other wireless systems. However, this process is beyond the scope of this paper, as these technologies hold no significance in this experimental setup.

The rest of this chapter presents the different implemented detection methods. These methods include EMG signal detection, a foot pressure sensor and eye blink recognition.

1.1 EMG signal detection

The first approach considered for detection involves electromyography signals (EMG).
Electromyography (EMG) is a technique used to measure and analyze the electrical activity of muscles. This technique has been widely used in both clinical and

research settings to assess muscle function, diagnose neuromuscular disorders, and monitor the progress of rehabilitation. This section addresses the various modalities of electromyography, including surface EMG, intramuscular EMG, high-density EMG, and dynamic EMG, and their applications in different fields. We will also discuss the advantages and limitations of each modality [25].
The detection of EMGs will be elaborated upon in more detail in chapter 2.

To implement this method, the guitarist is required to attach EMG electrodes to their body and undergo training for a precise muscle movement. If executed effectively, the electrodes successfully capture and detect the EMG signal, which can then be further processed to serve the intended purpose.

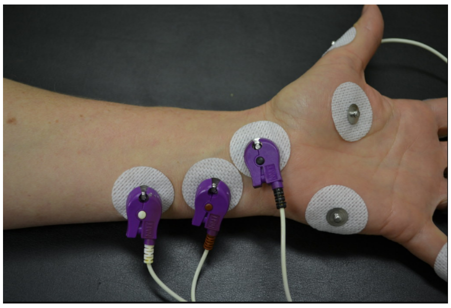
Naturally and as stated before, the primary objective of this remote activation is to grant musicians the freedom to move around and dance on stage without the need to return to the pedalboard. However, these movements requires a substantial number of muscle contractions, we hence need to isolate a particular contraction to be designated as the trigger signal. Consequently, this problem has implications for the choice of body location for electrode placement.

Isolating a specific contraction proves to be a considerable challenge, given the multitude of muscles engaged during activities such as walking, dancing, and playing the guitar. A possible alternative to this isolation involves implementing an intensity threshold which the muscle contraction must reach to be detected as the trigger signal. This approach would likely need extensive training, as executing a muscle contraction with the necessary strength during a live stage performance, precisely timed, can prove to be quite challenging given that this movement may not be natural and can possibly interfere with the guitarist's playing.

1.1.1 Different types of EMG

Surface EMG

Surface EMG is performed by placing non-invasive electrodes on the skin close to the muscle of interest to measure the electrical signals which trigger the contractions. Subsequently, the electrodes are linked to an amplifier, tasked with amplifying the signals for measurability and noise concerns.



Pros

- Non-invasive: Surface EMG is a non-invasive technique that does not require the insertion of needles into the muscle. This characteristic renders it notably more comfortable and less intrusive for patients, especially musicians.
- Accessibility: Surface EMG is a widely available technique that is easy to use and does not require excessively specialized equipment.
- Cost-effective: Surface EMG is a relatively low-cost technique compared to other electromyography modalities. This is primarily due the simplicity of the required material, as discussed earlier.
- Result-effective: Surface EMG can effectively provide information about overall muscle activity.
- Portable: Surface EMG devices are portable, enabling their utilization for measuring muscle activity in any location.

Cons

- Signal quality affected: Surface EMG being performed with electrodes on the skin, it is important to note that the signal might undergo alterations due to factors such as skin impedance and external noise.
- Cannot provide detailed information: Surface EMG measures the electrical activity from a distance making it possible for the electrodes to detect activity

from nearby muscles. Hence it cannot provide detailed information about individual motor units or muscle fibers.

- May be influenced by external factors: Surface EMG recordings may be affected by multiple factors such as temperature, humidity, and electrode placement, which can alter its accuracy. This can however be compensated by a calibration phase.

Intermediate conclusion This technique holds promise, characterized by its user-friendly nature, portability, and cost-effectiveness. However, it remains essential to determine whether the attainable level of accuracy meets the required standards [21].

Intramuscular EMG

Intramuscular EMG is performed by the insertion of a fine needle electrode into the muscle tissue to measure the electrical activity directly from the muscle fibers. After the electrode is positioned within the muscle tissue, it proceeds to record the electrical activity during various muscle contractions or periods of rest. The resulting signal can be analyzed to determine the firing patterns of individual motor units and their recruitment by the nervous system.

Pros

- Accurate measurements: Intramuscular EMG provides more precise measurements compared to surface EMG, largely due to its diminished susceptibility to factors such as skin impedance, noise, external factors and concurrent activity from neighboring muscles.

- Useful diagnostic tool: Intramuscular EMG is commonly used in clinical settings to diagnose and monitor neuromuscular disorders such as myopathy, myasthenia gravis, and neuropathy [24].

- Useful research tool: In research, Intramuscular EMG is employed to delve into muscle function and fatigue, and to explore the impact of diverse interventions on muscle activity.

Cons

- Invasive procedure: The insertion of the needle electrode can cause discomfort and occasionally, a small amount of bleeding.
- Expertise required: Intramuscular EMG requires specialized training and expertise to perform, as the insertion of the needle electrode requires skill and precision as well as specialized equipment. It is not a portable procedure.
- Limited applicability: Intramuscular EMG is not suitable for all types of muscles, and may be challenging to perform in certain areas of the body.
- Costly: Intramuscular EMG equipment can be expensive, making it less accessible.

Intermediate conclusion This technique appears to be less suited for our specific application. The constraints imposed are notably significant for an unnecessary gain in precision [24].

High-density EMG

High-density EMG (HD-EMG) is a type of surface EMG where a high amount of electrodes, typically between 64 and 256, are placed on the skin of the patients. This technique provides more detailed and localized information than surface EMG. The electrodes are arranged in a grid pattern, allowing for the measurement of muscle activity at multiple locations simultaneously. The electrical signals from each electrode are recorded and used to generate a map which can provide information about the location and intensity of muscle activity during various movements or tasks.

Pros

- Accurate measurements: By using a large number of electrodes, the signal-to-noise ratio is increased reducing the noise impact. The activity of nearby muscles can be more effectively identified, allowing for more detailed and localized overall measurements.

- Detailed muscle maps: The grid pattern of electrodes used in high-density EMG allows for the creation of detailed muscle maps that can provide valuable information about muscle function and coordination.

Cons

- Costly: High-density EMG equipment can be expensive, making it less accessible.
- Data processing requirements: The large amount of data generated by HD-EMG recordings can be time-consuming and computationally intensive to process and analyze.
- Limited applicability: High-density may not be suitable for all types of muscles or movements, and may be challenging to perform in certain areas of the body.

Intermediate conclusion This technique would also be unsuitable for our project, given that the objective of pedal activation is instantaneous response. Too much added processing time would undermine the viability of its implementation [10].

Dynamic EMG

Dynamic EMG (dEMG) measures the electrical activity of muscles during dynamic movements, such as walking, running, or lifting weights. It can be performed using invasive or non-invasive electrodes connected to a wireless transmitter to let the patient freely perform the movement.

Pros

- More realistic measurements: When patients engage in everyday movements, dynamic EMG offers a more authentic depiction, yielding results that closely mirror real-life scenarios.
- Muscle coordination: Dynamic EMG can be used to study the coordination between muscles during the movements.
- Movement analysis: Dynamic EMG can be combined with other motion analysis techniques to provide a more comprehensive understanding of movement patterns and muscle function.

Cons

- Data processing requirements: The large amount of data generated by dEMG recordings can be time-consuming and computationally intensive to process and analyze.
- Limited applicability: Dynamic EMG may not be suitable for all types of movements or activities, and may be challenging to perform in certain areas of the body.
- Technical challenges: Dynamic EMG requires specialized equipment and expertise to perform.

Intermediate conclusion As highlighted earlier, due to the time-consuming nature of processing information in dynamic EMG, it would not be adequately suitable for our application [18].

Final choice

Based on the intermediate conclusions, it becomes evident that surface EMG is the preferable choice. The potential decrease in accuracy, in comparison to other techniques, is not a concern for our application. Our primary requirement revolves around obtaining a trigger signal, rather than seeking the utmost precision or localized data. The triggering contraction has to be significantly intense to be distinguishable from an incidental one. It is therefore safe to assume that the precision of surface EMG is satisfactory.
Furthermore, it is the simplest to implement and a detailed real-life comparison would be too time consuming and expensive for this application.

1.2 Foot pressure detection

The second triggering method that was considered involves employing a pressure sensor positioned within the guitarist's shoe. In this scenario, the musician would need to exert sufficient pressure on the sensor to activate it as the trigger.

Once again, the challenge of distinguishing incidental pressure arising from activities like walking, dancing, or jumping from the intended trigger signal emerges. To address this, a pressure threshold is implemented. Consequently, the musician would need to exert a forceful kick against the ground, surpassing the typical pressure applied during walking, jumping, or dancing, in order for the sensor to effectively detect the trigger.

This solution resembles the classical approach of the footswitch on the pedal, with the primary distinction being the requirement for an increased level of force during the foot kick on the ground.

1.3 Eye blink detection

Blinking holds significant potential as a communication method, offering a straightforward means of generating a trigger signal. To implement this, the guitarist would need to have specialized glasses equipped with blink detection capabilities. In the context of this virtual reality experiment, the headset itself includes an integrated eye-tracking system that can serve this purpose [12].

The same challenge as encountered with EMGs and foot pressure detection arises here. Namely, a trigger blink should be differentiated from an incidental one. In this situation, adopting a pattern detection mechanism can serve as a viable solution. The system would need to identify a repeated pattern of blinks rather than relying on a solitary instance. However, this introduces a latency that can pose a challenge for the musician. The effect must be precisely activated at the intended moment requiring the musician to anticipate timing.

Alternatively, another approach involves maintaining closed eyes for a defined duration and utilizing this sustained closure as the trigger signal, triggering an action if the eyes are kept shut for longer than a predetermined threshold.
Nonetheless, the latency issue remains but incidental triggering is less likely.

1.4 Other possibilities

The final concept involves employing position tracking sensors to identify a precise movement. In the context of the VR experiment, the trackers within the VR set's controllers can be utilized for this purpose. In a practical application, the guitarist would need to attach the sensors to their hands or directly onto the guitar or gesture detection approach using cameras and computer vision [27].

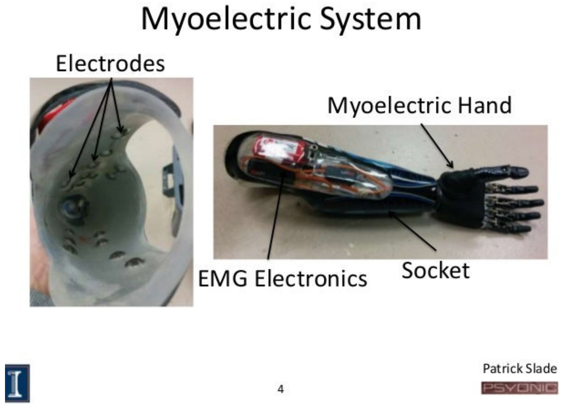
The triggering movement must possess distinctive characteristics to differentiate it from a random dance gesture. Moreover, it should not introduce any additional latency, be uncomfortable or interfere with the usual attitude of the guitarist on stage.
A variety of movements would undergo testing to determine the most suitable choice that aligns with its intended purpose. One could imagine customizing the gesture to the user's liking.
Finally, triggering different pedals is also possible via predefined gestures.

Unfortunately, due to constraints in terms of time and resources, this approach could not be implemented nor tested. We propose additional work to be conducted on this topic.

1.5 State of the art

1.5.1 Surface EMG in use

Surface EMG is currently used to develop myoelectric prostheses designed for individuals with upper limb amputations. These prostheses are equipped to identify the signals or patterns of muscle contractions that the patient intends to convey and subsequently respond correspondingly, such as executing actions like closing or openening the prothese. [14][29][26].



Athletes use surface EMG to examine their muscle fatigue levels during physical activities. This technique offers useful data, in combinations with methods like time-frequency analysis it can enhance the precision and reliability of fatigue assessment [9][31].

Surface EMG is commonly used during the rehabilitation process, aiding in the evaluation of muscle function and the ongoing tracking of progress throughout treatment [28]. Innovations like biofeedback training have emerged to enhance the effectiveness of surface EMG-driven rehabilitation approaches [23].

This technique is additionally employed for clinical purposes, serving as a tool to diagnose and oversee neuromuscular disorders [16]. Nonetheless, for this specific application, more precise techniques outlined in section 1.1.1 might be favored.

In the musical domain, surface EMG has been used to analyze muscle activity during instrument playing and singing. Biofeedback systems uses surface EMG to improve musician's techniques and prevent potential injuries [22] as well as monitor the effects of stage fright [6].

Sound signal have been created as an audio feedback to monitor muscular interaction by the detection of EMG and MMG (mechanomyogram) signals [13].

This project seeks to leverage surface EMG as a direct tool for live music performances, not for muscle activity monitoring. The positioning of electrodes on the body and the determination of intensity thresholds emerge as crucial factors in this endeavor.

1.5.2 Foot pressure sensor

Foot pressure sensors are currently being used for gait assessment and rehabilitation based on motorized shoes. They provide feedback to patients and healthcare professionals to improve walking mechanics and address issues related to injuries or conditions [2]. It can also be used for sports performance monitoring.

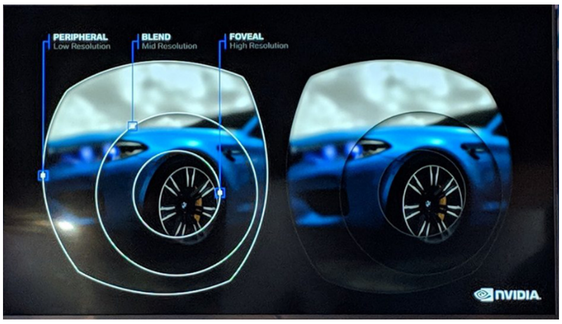
Foot pressure sensors are integrated into prosthetic limbs and orthotic devices to create more natural and adaptive movements, enhancing user comfort and mobility [4].

Foot pressure sensors are also being used for human-computer interactions as well as in gaming applications [11].

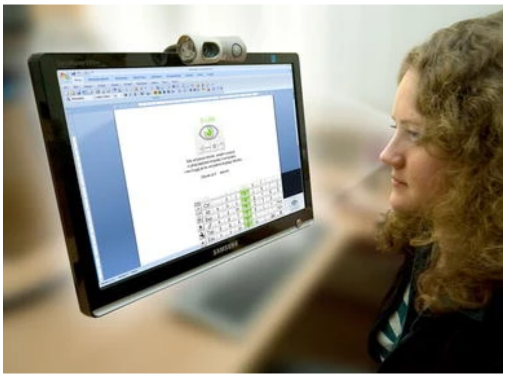
Foot pressure sensors can help monitor balance and stability in elderly individuals, assisting in fall prevention strategies and promoting healthy aging [8].

1.5.3 Eye blink recognition

Eye blink recognition and gaze data, are already in use in applications such as eye tracking devices for augmented and virtual reality. This feature allows for character control, interaction, or enhancing the immersive experience [1].



Experiments were also conducted about user-computer interactions using eye blink recognition and eye gaze data. Users may for example use long blink or patterns to load and navigate web pages, controlling the mouse cursor or even turn the computer off [19].



Eye gaze data and eye blinks recognition are used to recognize various emotions [20].

Coupled with electroencephalography (EEG), eye blink analysis can detect a driver's fatigue [30].

Chapter 2

Virtual Reality experiment

This chapter presents how the system was implemented and tested in virtual reality using Unreal Engine 5.
The complete implementation is illustrated on figure 2.1.

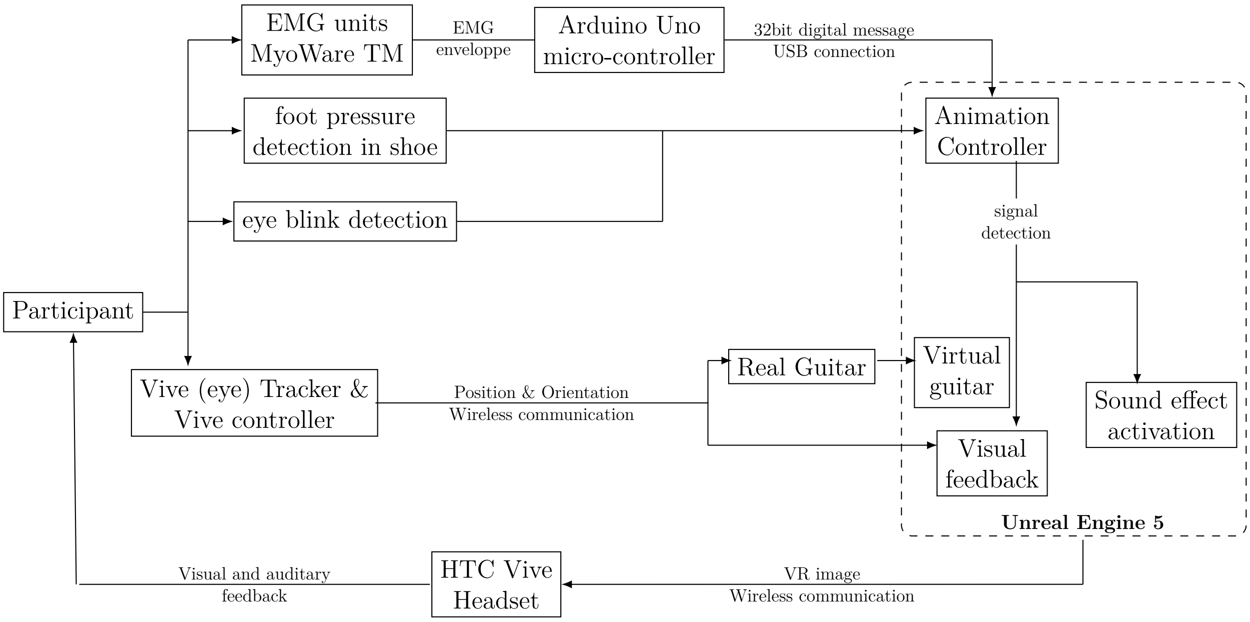


Figure 2.1: Complete system architecture

The participants are required to wear the VR headset and controllers, an additional installation will be necessary for the foot pressure and the EMG signal detection. The EMG signal data are processed by an Arduino Uno micro-controller before being transmitted to the software.
A physical guitar connected to the computer allow users to hear their playing

as well as the effect activation on a successful triggering detection, this will be described in chapter 4. All of this is processed by the VR environment which also provide visual and audio feedback.

This implementation provided users with the opportunity to test each of the discussed solutions within a consistent environment, enabling them to make objective and direct comparisons.

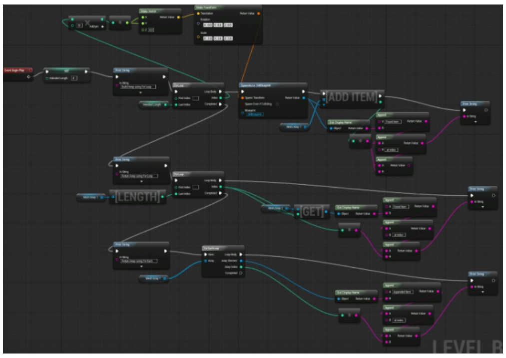
A physical guitar is seamlessly connected to the computer, functioning as an "in-game" microphone that allows participants to audibly hear their playing and the triggered effects. During the experience, the controllers remain securely fastened to the wrist, ensuring precise tracking and synchronization.

2.1 Unreal Engine 5

Unreal Engine (UE) is a 3D graphics game engine. Initially developed for First Person Shooter games, the software now released multiple powerful tools for other types of 3D creations such as films, architecture and Virtual Reality. The fifth generation of Unreal Engine is currently accessible and has been used for this project.

Development within UE5 offers the flexibility of utilizing a traditional programming language, `C++` specifically in this version, or opting for the Blueprint visual scripting system. This approach is more visual, hence easier to understand for individuals unfamiliar with coding, and minimizes the divide between technical artists, designers, and programmers.

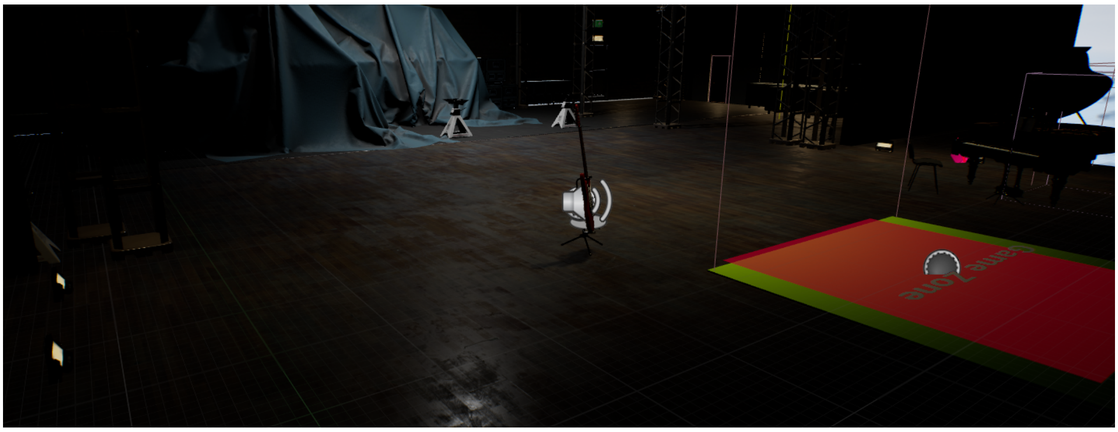
Blueprint is a visual scripting system, which uses common scripting elements (loops, conditions, variables and statements) and represents them as a graph of nodes with inputs and outputs. Using an extensive array of nodes and variations, Blueprint can be used as an easier alternative to `C++`.



2.2 Implementation of the experiment

2.2.1 Environment creation

A virtual concert stage was constructed using free 3D assets available in Unreal Engine. This immersive environment enables users to envision themselves within a real-life concert setting. Within this virtual realm, participants visualize themselves holding a guitar, and when successfully triggering an effect, they receive both auditory and visual feedback.



Each participant assessed every proposed solutions by progressing through separate stages. The subsequent stages were introduced only once all assignments within the ongoing stage had been accomplished.

To perform objective measurements of the user's ability with each mode of interaction, a test game was introduced at the conclusion of each level. The game displays the user's performance during the test in the form of a score. The game's mechanics and the design composition of each level will be further detailed in chapter 4.

2.2.2 Trigger signals

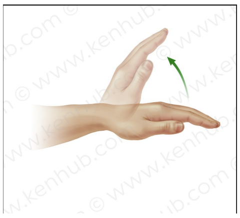
Each solution functions as an on/off trigger, activating or deactivating the effect. This mechanism operates as a binary switch, i.e. a boolean variable (`True` or `False`) in the implementation.

In this section we will discuss how the trigger signals were chosen.

EMG signal detection

The intensity of the EMG signal corresponds directly to the strength of the contraction exerted by the muscle where the electrodes are positioned. A numerical threshold converts this signal into an on-off switch.

Electrode location: Electrodes need to be positioned at an optimal location on the body. Upon consideration, the right forearm was selected, measuring the user's wrist extension. This movement is not a common one for a guitar player yet not too troublesome to realize while playing, making it an adequate choice as the trigger for our application.



The positive and negative terminals should be positioned on the muscle that contracts during the extension, while the ground terminal needs to be placed on an area where no EMG signals can be measured, i.e. close to a bone, in our case the elbow.

Figure 2.2: Illustration of the placement of the electrodes on the wrist extension muscles (missing the ground terminal) [15].

Foot pressure sensor

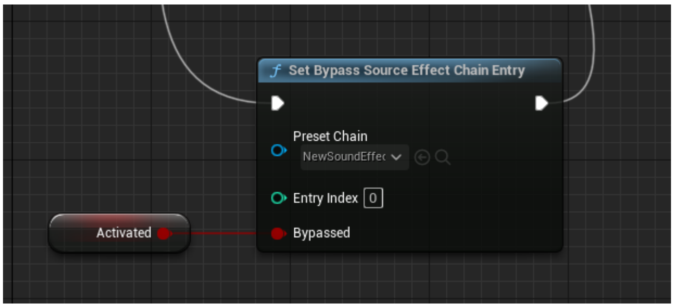
The strength of the received signal fluctuates according to the pressure applied to the sensor. In order to differentiate the intended signal from activities such as walking, dancing, or even jumping, it becomes imperative to establish a threshold.

Eye blink detection

Two distinct triggering mechanisms have been integrated, leaving the choice to the user. The choices encompass pattern recognition, requiring three consecutive blinks within a two-second interval, and a predefined closure duration of 1.5 seconds. These two options could be expanded upon, or modified by offering the user the possibility to customize the blink pattern or the minimal duration that they have to keep their eyes closed.

2.2.3 Blueprint scripts

Upon virtual guitar pickup, the 'audio capture' component linked to it is activated, thereby engaging the microphone connected to the real guitar. UE5 proposes the incorporation of an effect chain into the audio capture signal, where the distortion effect finds its application. Implementation becomes a matter of enabling or disabling the bypass boolean variable within the effects chain to toggle the activation or deactivation of the distortion. By design, the bypass is initially engaged to ensure an unaltered audio signal.



The following portion of this section provides a more detailed description of the implementation for each individual trigger.

EMG signal detection

The EMG signals are collected by homemade EMG controller based on the work of Lucas El Raghibi [14]. This controller is composed of EMG units MyoWare^{TM} and an an Arduino Uno micro-controller. EMG units transmit an EMG envelope to the Arduino, which provide the collected data to the main computer where they were processed by the UE5 software using the SERIALCOM plugin[1].
A block diagram of the implementation is proposed on figure 2.3.

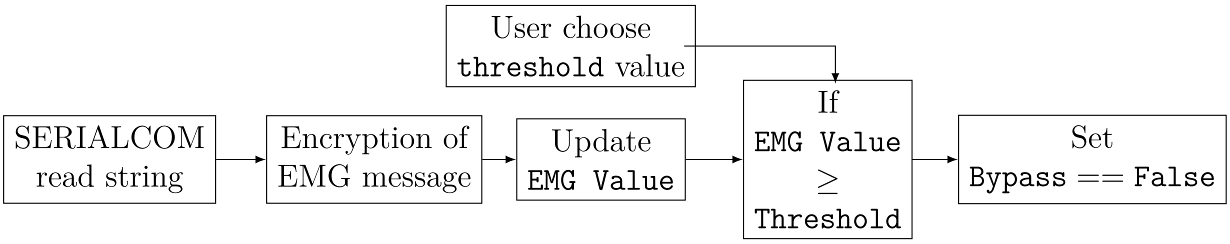
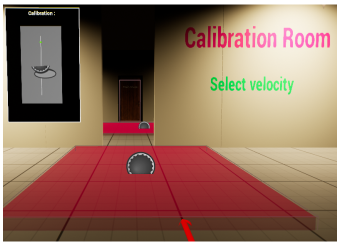


Figure 2.3: Simplified version of the implementation of the EMG trigger signal.

Foot pressure sensor

Instead of using a physical pressure sensor, the VR headset controllers were used in conjunction with a collision box in UE5. Collision boxes are 3D shapes that can detect when a physical element (here the controller), intersects them.



Moreover, the system is capable of capturing the velocity of the component upon collision with the box. The trigger was implemented as a threshold on this velocity.

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[1] The SERIALCOM plugin is "An Arduino compatible plugin that allows connecting any Arduino to Unreal Engine, but most importantly, it allows any Serial Communication device to interact directly to and from Unreal Engine", (VIDEOFEEDBACK, `https://github.com/videofeedback/Unreal_Engine_SerialCOM_Plugin#readme`)

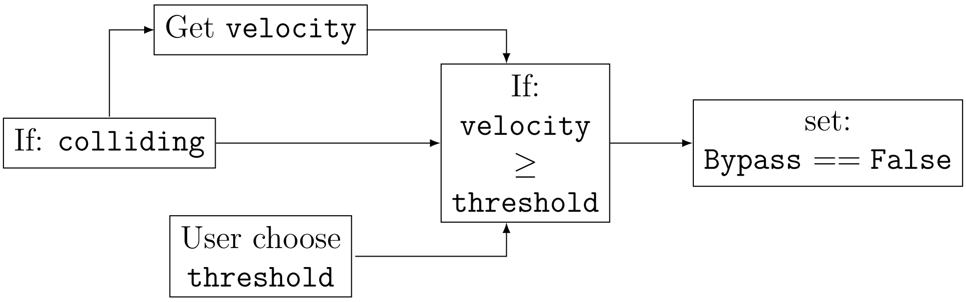


Figure 2.4: Simplified version of the implementation for the eye blink detection solutions.

The threshold value needs to surpass the average velocity attained immediately before making contact with the floor when jumping or dancing.

Eye blink detection

The VR hardware employed, namely the HTC Vive HMD, is equipped with an eye-tracking system. This eye-tracking functionality facilitates the detection of blinks by analyzing the gaze data it generates.
As previously discussed, users have the option to select between a sustained blink or a recognizable pattern. A simplified representation of each implementation is depicted in Figure 2.5, with the pattern recognition illustrated in the upper graph and the closure time solution provided in the lower section.

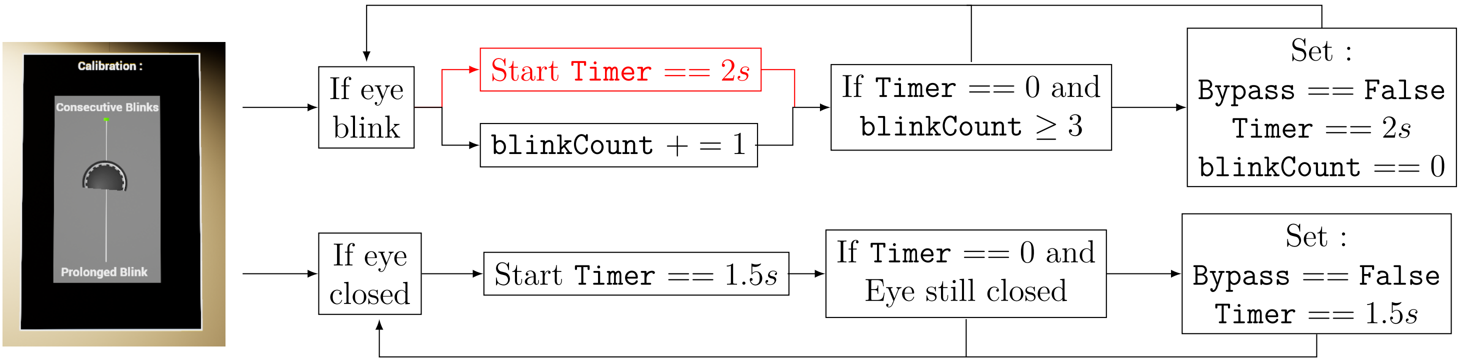


Figure 2.5: Simplified version of the implementation for the eye blink detection solutions.

Chapter 3

Methods of the experiment

The following chapter details the methods used to conduct the experiment and acquire the useful objective and subjective data.

3.1 Participant details

The complete setup was intentionally tested by a small group of individuals. The participants selected for this evaluation were approximately 24 years old on average. Due to time constraints, the testing pool was limited to only four participants. Despite this limitation, efforts were made to ensure diversity in the selection of profiles:

- One experienced guitarist familiar with VR technology
- One experienced guitarist with limited experience with VR technology.
- One beginner guitarist familiar with VR technology
- One beginner guitarist with limited experience with VR technology.

The experienced guitarists were accustomed to the conventional activation system of pedal effects.

3.2 Experimental setup

Hardware The complete system has been described in chapter 2. Each participant was equipped with the HTC Vive head-mounted display (HMD) along with the corresponding controllers.
Throughout the EMG solution testing phase, the Arduino with the electrodes was

positioned on the participant's right forearm. In the evaluation of the foot pressure solution, one of the controllers was securely fastened to the designated foot of each participant.

To infuse an authentic dimension into the experiment, participants held a genuine electric guitar while engaging with the system. The controller was then securely attached to their wrist. To enable the computer to process the audio signal emanating from the guitar and transmit this data to the program, an audio interface was used. In this instance, a Focusrite audio interface was employed. Both auditory and visual feedback were seamlessly delivered through the head-mounted display (HMD). A short overview of the hardware setup is proposed on figure 3.1 while a more complete depiction of the whole system architecture was given on figure 2.1.

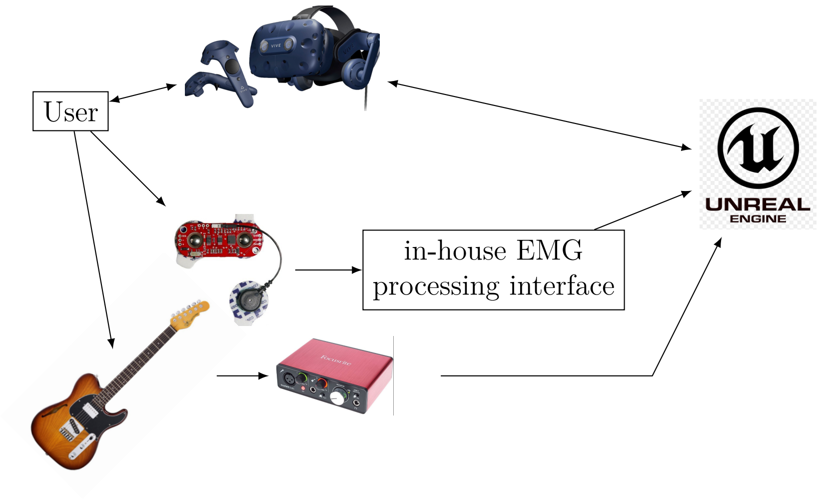


Figure 3.1: Hardware setup.

Software Participants are fully immersed within a virtual environment, traversing multiple rooms to successfully navigate each level, which corresponds to a distinct solution. Each level adheres to a uniform guideline, as illustrated in Figure 3.2, ensuring a consistent and coherent testing experience throughout the experiment.

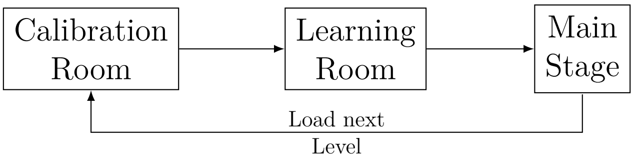


Figure 3.2: Guideline of each level

- EMG solution : Participants start within a calibration room, wherein the real-time intensity of signals captured by the EMG units is showcased. A slider facilitates the manual adjustment of the desired minimal threshold value. Whenever a signal surpasses this threshold, a visual response is triggered: a red light transitions to green, thereby providing immediate and discernible feedback.

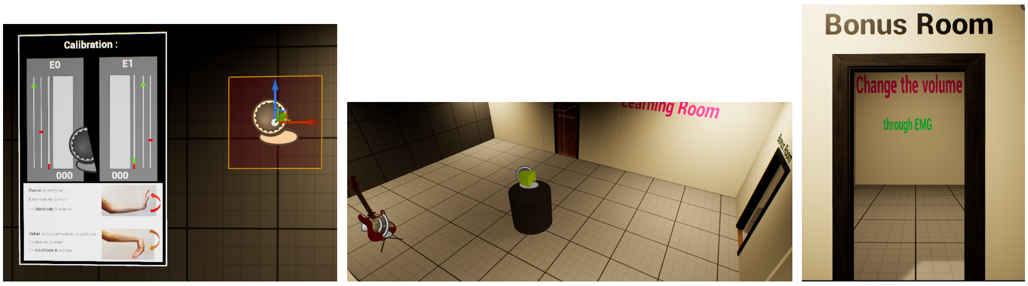
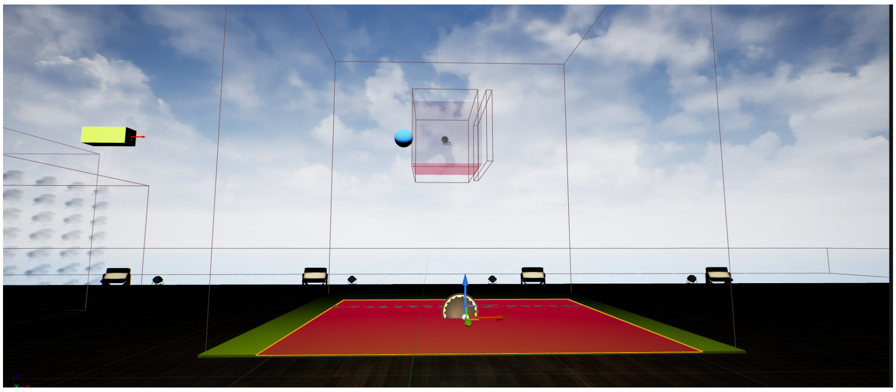


Figure 3.3: Left: Calibration of EMG intensity threshold. Middle: Learning room. Right: Bonus room

Subsequent to the calibration room, participants progress to a chamber where a rotating cube illustrates the intensity of the EMG signal. The velocity of this cube's rotation is directly influenced by the EMG signal's intensity, regardless of the threshold. This element is primarily designed to acclimate the user to their individual strength associated with the EMG signal intensity. Once this phase is completed, participants can proceed to pick up the virtual guitar, triggering the activation of the audio capture. This let the participants undergo the training phase for the following main stage experience.
Exceptionally an additional bonus room is accessible to participants. This special room grants participants the ability to exert continuous control over the volume of the virtual guitar. This control is facilitated through the modulation of EMG signal intensity, deviating from the conventional on/off trigger mechanism employed elsewhere in the experiment.

With the training phase concluded, participants are encouraged to advance to the main stage. This is where the game measuring their ability with the given mode of interaction takes place. This mini-game challenges users to execute the effect trigger precisely at the right moment. Participants observe balls traversing a designated area, denoting the temporal window for activation. The velocity and appearance of these balls are completely random. An identical mini-game configuration persists across all solutions, ensuring a standardized testing environment.



Upon successful completion of the mini-game, participants are required to navigate to the designated "load next level" zone in order to advance to the following solution.

- Foot pressure detection : Once more, participants begin in a calibration room. Here, they have the opportunity to select the velocity threshold that must be met to activate the effect upon entering the collision box. A color-shifting collision box serves as a practical means for testing the effectiveness of their chosen velocity threshold and achieving successful activations.

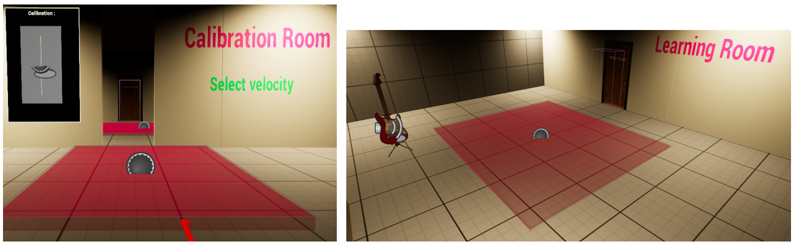


Figure 3.4: Left: Calibration of foot pressure velocity threshold. Middle: Learning room.

They may then pick up the virtual guitar and start practicing while playing until they feel confident enough to try the mini game on the main stage before going to the next level.

- Eye blink detection : Within this calibration room, participants are presented with a choice between the two trigger options. A visual feedback mechanism is implemented, where a red plane transitions to green upon successful activation. Additionally, a blink counter offers real-time feedback, indicating progress within the pattern recognition trigger. This counter resets to 0 at the conclusion of the 2-seconds window.

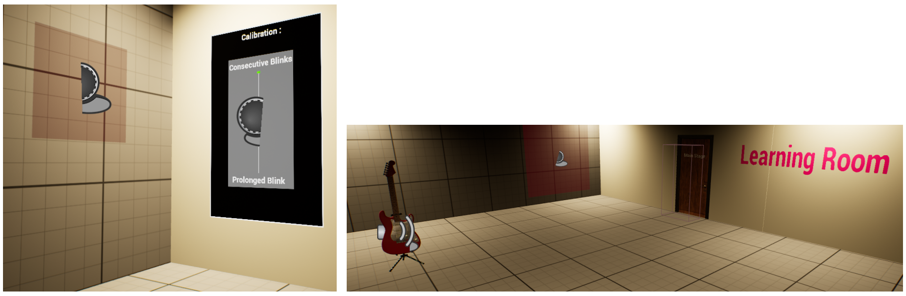


Figure 3.5: Left: Choice of the type of blink recognition desired. Middle: Learning room

Participants then transition to the learning room, where they retrieve the virtual guitar and participate in the final mini-game on the main stage. This marks the conclusive phase of the experiment.

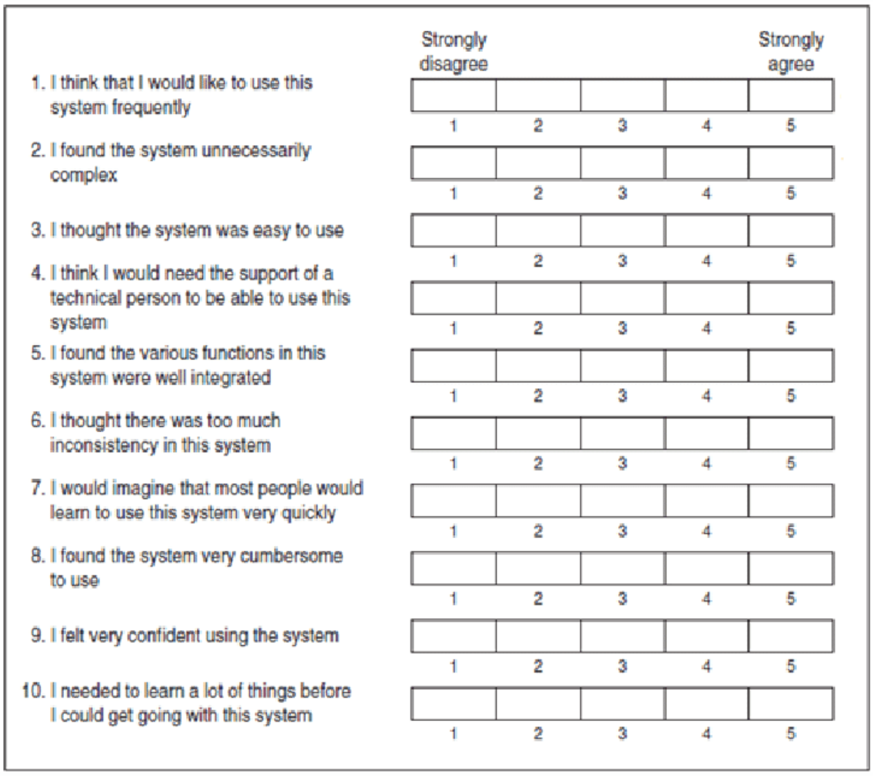
3.3 Experimental trials

Each session started with a comprehensive theoretical introduction to the system, clarifying the underlying motivations driving this experiment. Subsequently, participants were presented with an initial opinion survey. This survey encompassed inquiries regarding the perceived necessity of such an application, their preferences concerning the most effective solution, as well as their personal familiarity with pedal effects and prior experiences with VR experiments.

Following the survey, participants underwent the setup installation process. This entailed equipping participants with the in-house built EMG Arduino interface, followed by their immersion into the virtual reality environment. Participants were then given the physical guitar, while the headset controllers were securely affixed to their wrists.
Upon the conclusion of the EMG experiment, the EMG interface was removed. Subsequently, a controller was affixed to the ankle to test the foot pressure solution. The eye blink solution required no additional installation, as all necessary components were already integrated within the HTC Vive HMD.

Subsequent to the experimental phases, participants were requested to complete a second opinion survey. In this survey, participants were asked to rank each solution based on their personal preferences, indicating which solution they found most suitable and least suitable for their needs. Additionally, participants were invited to express their opinions on the practicality of each solution for real-world applications.

Furthermore, an assessment of the virtualized device's usability was formally conducted following the VR sessions. Participants were requested to complete the System Usability Scale (SUS) questionnaire. This concise survey, consisting of 10 questions, serves as a reliable and expedient tool to gauge the overall usability of the system under study. Users rate their responses on a scale ranging from "strongly disagree" to "strongly agree". Notably, this survey is known for its robustness, even when dealing with limited sample sizes.



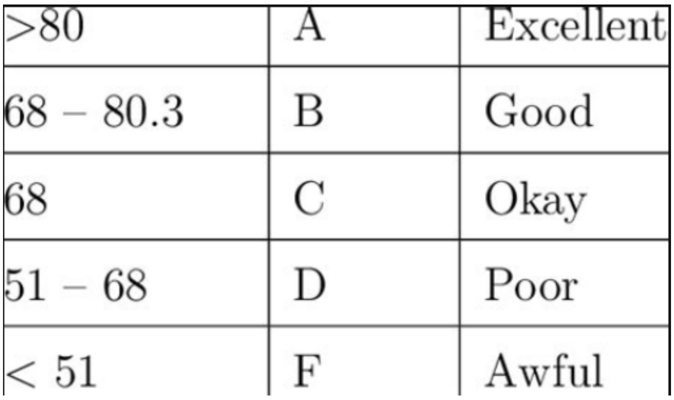
	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
2. I found the system unnecessarily complex	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
3. I thought the system was easy to use	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
4. I think I would need the support of a technical person to be able to use this system	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
5. I found the various functions in this system were well integrated	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
6. I thought there was too much inconsistency in this system	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
7. I would imagine that most people would learn to use this system very quickly	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
8. I found the system very cumbersome to use	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
9. I felt very confident using the system	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
10. I needed to learn a lot of things before I could get going with this system	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Figure 3.6: SUS questionnaire.

The resulting SUS score, ranging from 0 to 100, encapsulates the system's usability performance across effectiveness, efficiency, and overall user-friendliness. While each response corresponds to a numerical score within the 0 to 100 range, this score is not indicative of usability in terms of a percentage. The formula to compute the final score is given below [7].

$$\begin{aligned} &\text{With } X \text{ being the answer value } (1-5)\text{:} \\ \text{For odd-numbered questions } (i \text{ odd})\text{: } &\mathit{points}[i] = X - 1 \\ \text{For even-numbered questions } (i \text{ even})\text{: } &\mathit{points}[i] = 5 - X \\ \text{Sum all the points up then: SUM} &= \sum_{i=1}^{10} \mathit{points}[i] \\ \text{SUS score} &= \text{SUM} * 2.5 \end{aligned}$$

For a more detailed analysis of the SUS scores, an adjective scale comprising seven points can be employed to quantify acceptability. This scale incorporates descriptors such as "good," "ok," and "poor," providing insights into whether the usability is deemed "acceptable," "not acceptable," or falls within a "marginal" category. The typical SUS score is 68, indicating that a device with this score will be perceived as having an "okay" level of usability [5].

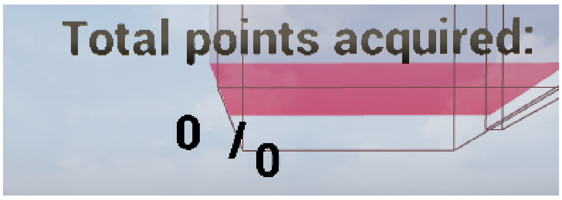


>80	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
< 51	F	Awful

Figure 3.7: Table of the SUS Scores and the corresponding adjectives.

3.4 Data collection and analysis

The mini-game on each main stage is designed to record scores based on accurately timed activations across 20 target balls. This setup provides quantifiable and objective data to complement the insights gathered from the opinion surveys.



Furthermore, each solution is assigned a score derived from the rankings provided in both the pre- and post-experiment opinion surveys. The top-ranked solution receives a score of 1, the second-ranked solution receives 0.5, and the lowest-ranked solution receives a score of 0. This scoring mechanism results in a maximum achievable score of 4 for each solution.
Lastly, the SUS scores of each solutions will be analyzed and discussed.

Chapter 4

Results of the experiment

In this section, the results of the experiment, namely the scores of the mini-games and the feedback given in the before/after opinion surveys, are presented and analyzed.

4.1 Objective mini-games scores

The mini-games implemented in the experiment consist of correctly timed triggers. The correct timing occurs when a moving ball enters a limited visible zone indicating when to activate the trigger. This way, objective data on the reliability of each solution could be collected.

The collective average score garnered by all participants for each solution is graphically depicted in Figure 4.1. Notably, out of 20 balls, 15 were accurately timed using the EMG solution, in contrast to 11 for the foot pressure sensor and 6 for the eye blink recognition.

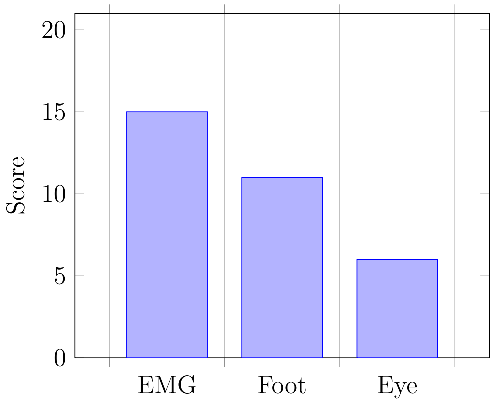


Figure 4.1: Average score for each solution achieved during the mini-game.

When the EMG signal detection arises as the most reliable solution, one might already try to explain the underperformance of eye blink recognition. As mentioned earlier, a pattern of eye blinks, as well as a closure time, induce latency. In the context of a correctly timed trigger, the participants hence had to anticipate this latency complicating the game.

4.2 Subjective survey reviews

Ranking of the methods. Each participants were asked to rank the solutions based on their appreciation and the efficacy of the system. This ranking earned each solution points as explained in the section 3.4.

A very interesting observation arising from the comparison between the before and after opinion surveys is the dynamic shift in participants' preferences regarding the ideal solution. Figure 4.2 represents the percentage of participants placing the corresponding solution in the first position in their ranking.

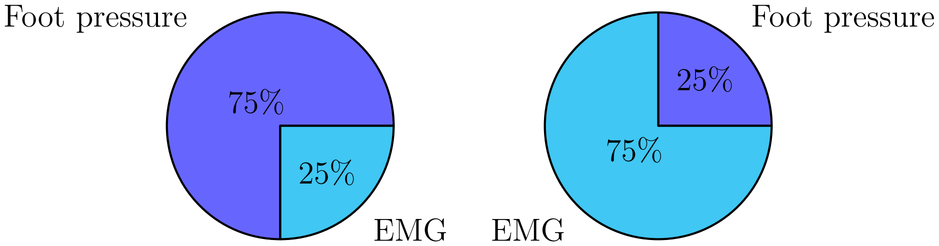


Figure 4.2: Left: Ideal solution before the experiment, Right: Ideal solution after the experiment.

Naturally, this phenomenon closely mirrors the ranking scores attained by each solution as illustrated in table 4.1.

Solution	Before	After
EMG	2/4	3.5/4
Foot pressure	3.5/4	2/4
Eye blinks	0.5/4	0.5/4

Table 4.1: Ranking score achieved by each solution before and after the experiment

A particularly interesting feedback given concerning the EMG signal detection is the mechanism proposed in the "bonus room" wherein the volume was continuously adapted according to the EMG signal intensity. The participants proposed implementing the same mechanism for the amount of effect, in this case distortion, assigned to the audio signal for future development.

System Usability Scale (SUS). Concerning the SUS survey, participants filled it out four times: once for each solution, and once for the overall VR experiment.

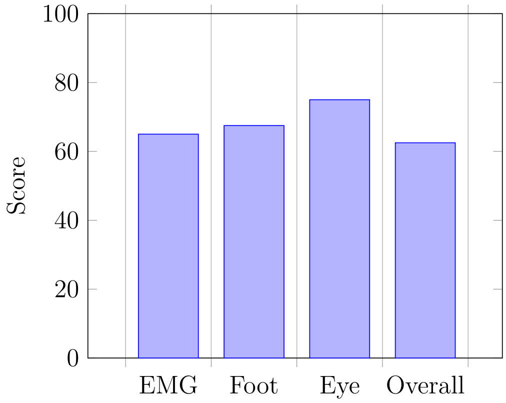


Figure 4.3: SUS score for each solution and the ovreall VR experiment

Interestingly, despite its comparatively lower reliability, the eye blink recognition solution garnered a SUS score of 75, corresponding to a "good" descriptor on the SUS scale. In contrast, both the EMG and foot pressure sensor solutions received scores below the marginal threshold of 68, with ratings of 65 and 67.5, respectively, categorizing them as "poor" in terms of usability.
The overall VR experiment also scores a "poor" descriptor with a 62.5 SUS score.

Chapter 5

Discussion

The objective for this study was to develop remote activation of audio guitar effects. Three different mechanisms , EMG signal detection, foot pressure sensor and eye blink recognition, were successfully implemented. The different systems were evaluated in a virtual reality model.

5.1 Results interpretation

5.1.1 Correlation between objective and subjective data

An evident correlation emerges, linking the participants' preferred ideal solution, the ranking score derived from the post-experiment opinion survey, and the average mini-game score. The EMG solution unequivocally emerges as the most reliable among the alternatives, closely followed by the foot pressure sensor. Conversely, the eye blink solution failed to satisfy the participants.

However, an inconsistency becomes apparent when examining the SUS scores. Curiously, the eye blink solution achieved the highest SUS score, while the EMG solution scored the lowest in this regard. No discernible correlation between the average mini-game scores and the SUS scores can be established.
This inconsistency gains clarity upon scrutinizing the opinion survey responses provided by participants. Their feedback encapsulates their subjective assessment of each solution, as well as suggestions for potential improvements.
It appears that:

- The in-house built EMG interface has been noted as cumbersome by participants. Additionally, challenges were encountered with the adhesion of electrodes to the arm, particularly in cases where participants had hair. This issue hindered optimal usability, highlighting a practical concern that may have contributed to the solution's lower ranking in terms of usability and satisfaction.

- Securing the controller on participant's ankle for the foot pressure sensor solution proved to be more troublesome than expected as it occasionally dislodged and required reattachment. Moreover, the chosen velocity axis for this solution is the vertical z axis. Given that the natural movement of a foot kick on the ground is never purely vertical, certain kicks were not detected, despite the overall velocity surpassing the threshold. This discrepancy significantly contributed to the diminished SUS score for this solution.
- The eye blink recognition solution required no explicit setup installation and demanded minimal training to activate the effect, rendering it the most straightforward solution. This simplicity contributed to its "good" System Usability Scale (SUS) descriptor. The only drawback observed is the delay introduced by multiple or prolonged blinks when aiming for a precisely timed trigger.

Regarding the SUS score for the entire VR experiment, feedback indicated that while the system functioned adequately, participants did not consider virtual reality to be the optimal platform for testing. Participants expressed concerns about some unnecessary complexities introduced by the virtual reality environment, i.e. for example, the need of the controllers to be able to move when these controllers are attached to the wrist when holding the guitar, in addition to experiencing instances of crashes and bugs during the experiment. These factors collectively contributed to a suboptimal usability rating for the overall virtual reality setup.

5.1.2 Statistical significance

The significance test consists in a p-value measure of how significantly better the users tented to perform with one method compared to another. To this end, if E, Y and F designate the random variables of the users's score for the EMG signal detection, the eye blink recognition and the foot pressure sensor respectively, then three new random variables (E-Y, E-F, F-Y) were defined as their pairwise differences. The mean of those differences was compared to zero with a student's T statistical test, giving a p-value.
A typical p-value of 0.05 is used as a threshold to determine the significance of a hypothesis [3] [17].

Variable	p-value	Explanation
E-Y	0.022	users score better with the EMG than the eye recognition
E-F	0.10	p-value not significant enough to make any assumptions
F-Y	0.033	users score better with the foot pressure sensor than the eye recognition

Table 5.1: p-value and interpretation for each solutions

Important note: Given the limited participant size of four, the application of statistical analysis within this context lacks meaningful statistical significance. Consequently, this section does not establish any conclusive evidence. This observation only reflects a potential tendency, necessitating further exploration through experiments resulting in more meaningful data.
Using statistical power analysis it is possible to determine the optimal participant sample size necessary to attain meaningful and pertinent data.

5.2 Limitations and future improvements

The EMG detection solution, proved to be the most reliable but it is important to acknowledge that it is not without its imperfections. This mechanism does exhibit certain limitations.
The hardware does present some challenges in terms of its bulkiness, and the electrodes face difficulties in maintaining a secure attachment to the arm, particularly during active arm movements such as those involved in guitar playing by the participants.
The signal quality yielded by the MyoMare^{TM} sensors falls short of that achieved by conventional myoelectric sensors, potentially influencing the accuracy of certain detections.
The experimental setup limited participants from engaging in extensive movement or dancing due to constraints associated with the wired connection requirements of the in-house EMG interface, the HTC Vive HMD, and of the guitar, all within the confined space of the room. As a result, the system was solely evaluated with participants who were required to maintain limited gestures. This circumstance introduces uncertainty regarding the viability of utilizing wrist extension as the designated trigger signal in real-world situations.
A new less troublesome version of the in-house built EMG interface could improve this experiment relevance.

The foot pressure sensor yielded moderately satisfactory results. Reviews indicated that the concept was interesting, primarily due to its resemblance to the

existing mechanism. However, it is essential to acknowledge that this approach also exhibited certain limitations.
Evaluating the foot pressure sensor within a VR context, where the controller was affixed to the participant's ankle, proved to be suboptimal. This setup encountered challenges as the controller occasionally dislodged, and its cumbersome nature posed additional difficulties during testing.
Since only the z axis was considered, certain kicks went undetected even when their velocity exceeded the threshold. This is because kicks are often not perfectly vertical and can deviate from that axis.
In a real-world application where an actual sensor is placed inside a shoe, it's crucial to ensure that the device provides a comfortable experience for the artist. However, this solution becomes impractical for artists who prefer to perform barefoot.

The eye blink recognition solution, despite receiving the highest SUS score attributed to its straightforward setup, did not succeed in the mini-games designed to assess its efficacy. This outcome can be attributed to the latency caused by consecutive blinks. Notably, this latency posed a challenge as users struggled to accurately anticipate the optimal moment for triggering a guitar audio effect, which requires precise timing.
Furthermore, in a practical real-life application, artists would be required to wear specialized glasses, which could potentially lead to discomfort and hinder their overall experience.

The overall VR experiment received feedback indicating that it was not yet an optimal platform for testing these mechanisms, with an exception for the eye blink solution due to the integrated eye tracking system of the HTC Vive HMD.
Virtual reality introduced certain unnecessary complexities. For instance, the requirement for controllers to facilitate movement within the VR environment posed challenges, as the controllers needed to be affixed to the wrist while holding the guitar. Additionally, the inclusion of virtual reality led to audio delays in guitar playing, as the signal necessitated processing by the program.

The empirical outcomes of the experiment conclusively demonstrated the efficacy of EMG signal detection for the intended application. In contrast, the recognition of eye blinks did not pass the tests and was therefore considered not reliable for this application.
However, as mentioned in section 5.1.2, an experiment with the optimal sample size should be concluded in future work in order to statistically prove this tendency.

The outcomes holds promises for a practical implementation in real-life scenarios. Feedback collected through the opinion survey revealed that participants recognized the value and necessity of such devices. Particularly, this remote activation mechanism could be invaluable for low-budget artists who lack the resources to employ a sound engineer to trigger their effects on their behalf.

Participants expressed significant interest in the "bonus room", wherein the volume dynamically adjusted based on EMG signal intensity. They further recommended incorporating this concept into the audio effect level control, deeming it the most promising and effective mechanism among all the proposed solutions.

While this study centered on the activation of audio effects, it is worth noting that the functionality of the system could be extended. The same system could also be adapted to initiate loops[1] or start backing tracks[2], expanding its potential utility and applications. These ideas keep the initial motivation of this study to give the guitarists more freedom and autonomy when live performing on stage.
A notable gain in creativity may be achieved through a continuous adaptation accordingly to the EMG signal intensity. This however may require more precise material.

Lastly, since guitarists need multiple effects, each one activated or adapted at different moments of the concert, one could imagine a combination of each solution to increase triggering possibilities.
Each solution itself could also be adapted, here are some ideas:

- Creating a pattern of muscle contraction recognition system for the EMG solution when timing is less important (such as in between songs).
- Placing multiple pressure sensors on different parts of both foots.
- Allowing users to customize the blink recognition recording their pattern as different presets.
- Having a set of recorded gestures detected by tracking sensors or computer visions algorithm as proposed in section 1.4.

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[1] Loops in music refer to recurring segments of sound, typically a sequence of notes, rhythms, or melodies, that are repeated to create a consistent and repetitive pattern.

[2] Backing tracks in music are pre-recorded audio accompaniments that provide a foundation for live performances or studio recordings.

Conclusion

In this study, we embarked on a comprehensive exploration of remote activation mechanisms for audio guitar effects within a Virtual Reality (VR) environment. Our investigation encompassed various techniques, including EMG signal detection, foot pressure sensors, and eye blink recognition. Through rigorous testing and analysis, we uncovered valuable insights into the strengths and limitations of each mechanism.

The EMG signal detection mechanism emerged as the most effective solution, as well as proposing a noteworthy implementation of a volume adapter based on muscle intensity, demonstrating its potential for real-world implementation despite some inherent imperfections. However, challenges pertaining to hardware bulkiness and electrode stability were identified, underscoring the need for further refinement in ergonomic design.

The foot pressure sensor approach, while interesting, revealed both promising attributes and inherent limitations. Its performance was hindered by the current VR setup, suggesting that future iterations should consider alternative methods of implementation that cater to diverse performance styles, such as barefoot musicians.

The eye blink recognition solution, although exhibiting the highest System Usability Scale (SUS) score, encountered setbacks in reliability due to latency and timing issues.

Our study also shed light on the implications of using VR as a testing platform. While this environment showcased potential, particularly through the eye blink recognition solution leveraging HTC Vive's eye tracking system, it suffers from significant limitations including controller use during guitar playing and audio signal processing.
Accordingly, the use of VR as a testing platform for this type of study will require further important improvements.

In conclusion, this research serves as a "proof of concept" study to kick start future developments in remote activation mechanisms for audio guitar effects. As we move forward, it is imperative to address the identified limitations and further refine the proposed solutions, bearing in mind the comfort and preferences of artists. With the ever-evolving landscape of technology and music performance, our findings contribute to the ongoing dialogue surrounding innovative approaches to enhancing live musical experiences.

Conflict of interest. The author did take part in the experiment, being a guitarist himself. He however declared he tried to stay as unbiased as possible in the opinion surveys.

Additional note: In the development of this academic thesis, I received assistance from ChatGPT, an artificial intelligence developed by OpenAI. While this tool proved invaluable for research and information synthesis, it is important to emphasize that I am the primary and ultimate author of this work. Therefore, I take full responsibility for the content presented, including any potential errors or omissions.

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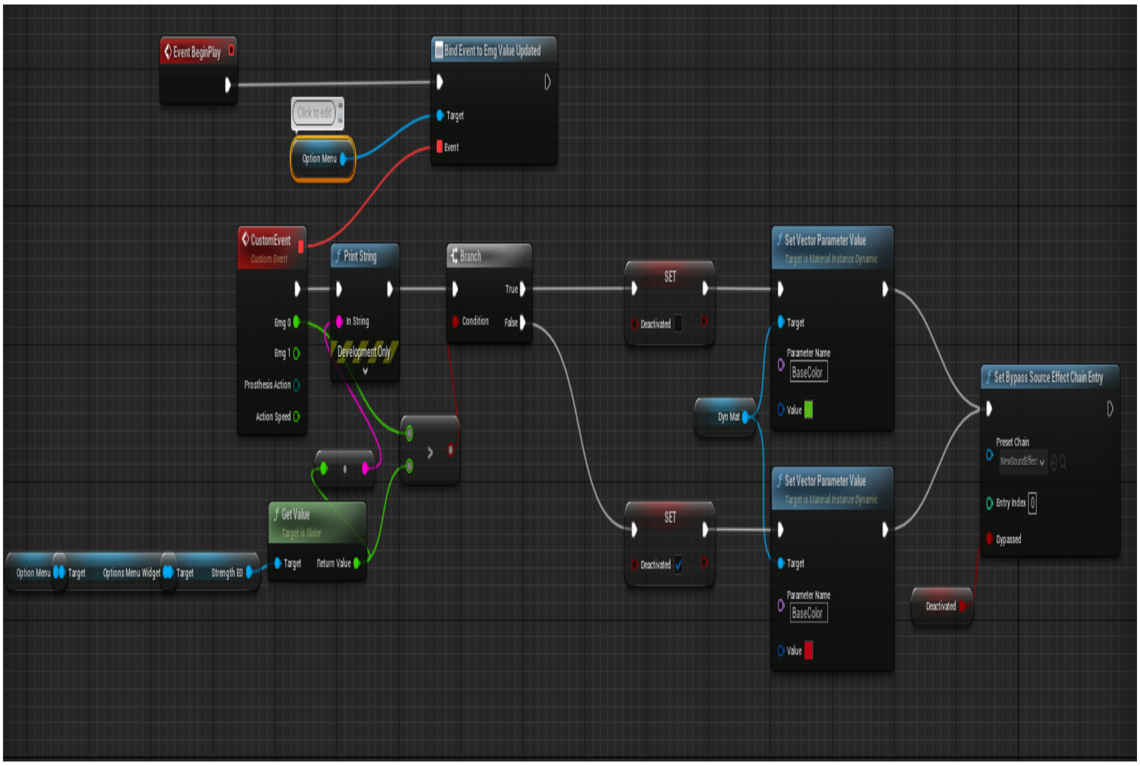
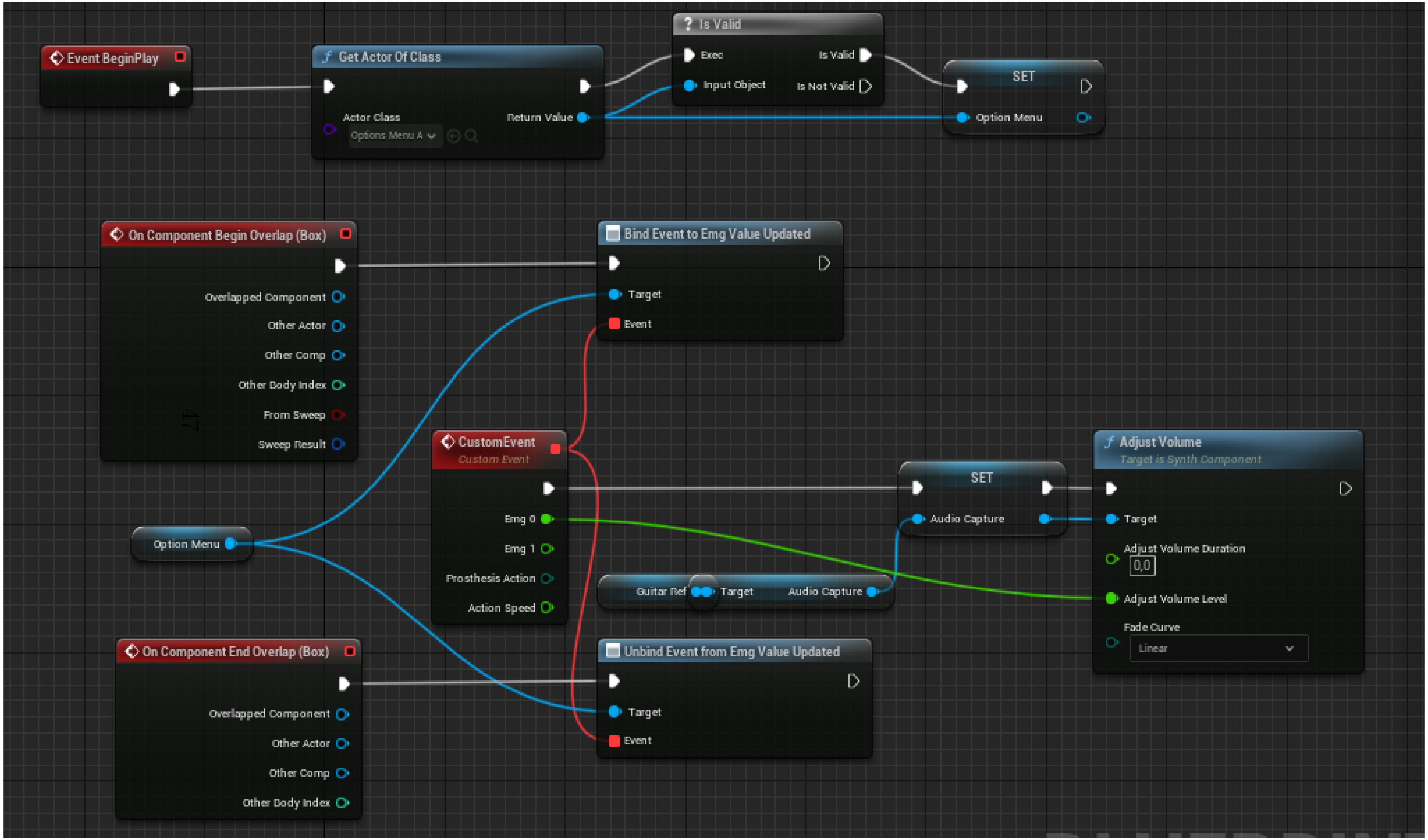
Appendix A

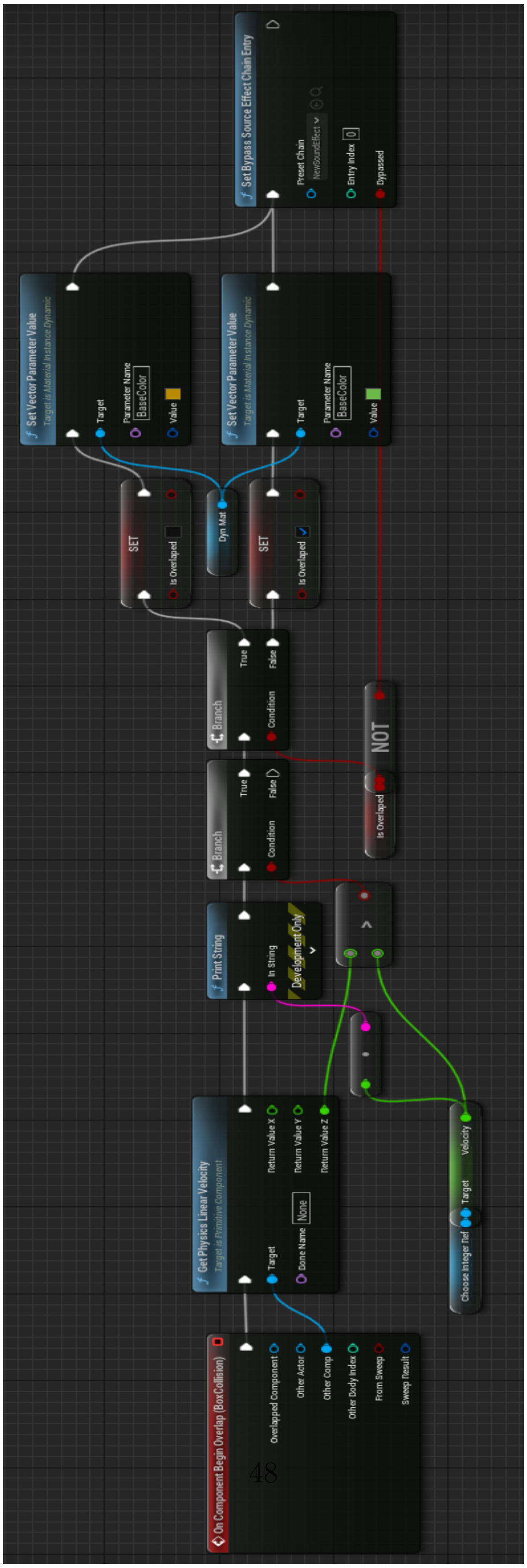
Blueprint Codes

A.1 EMG blueprint, trigger and continuous volume change

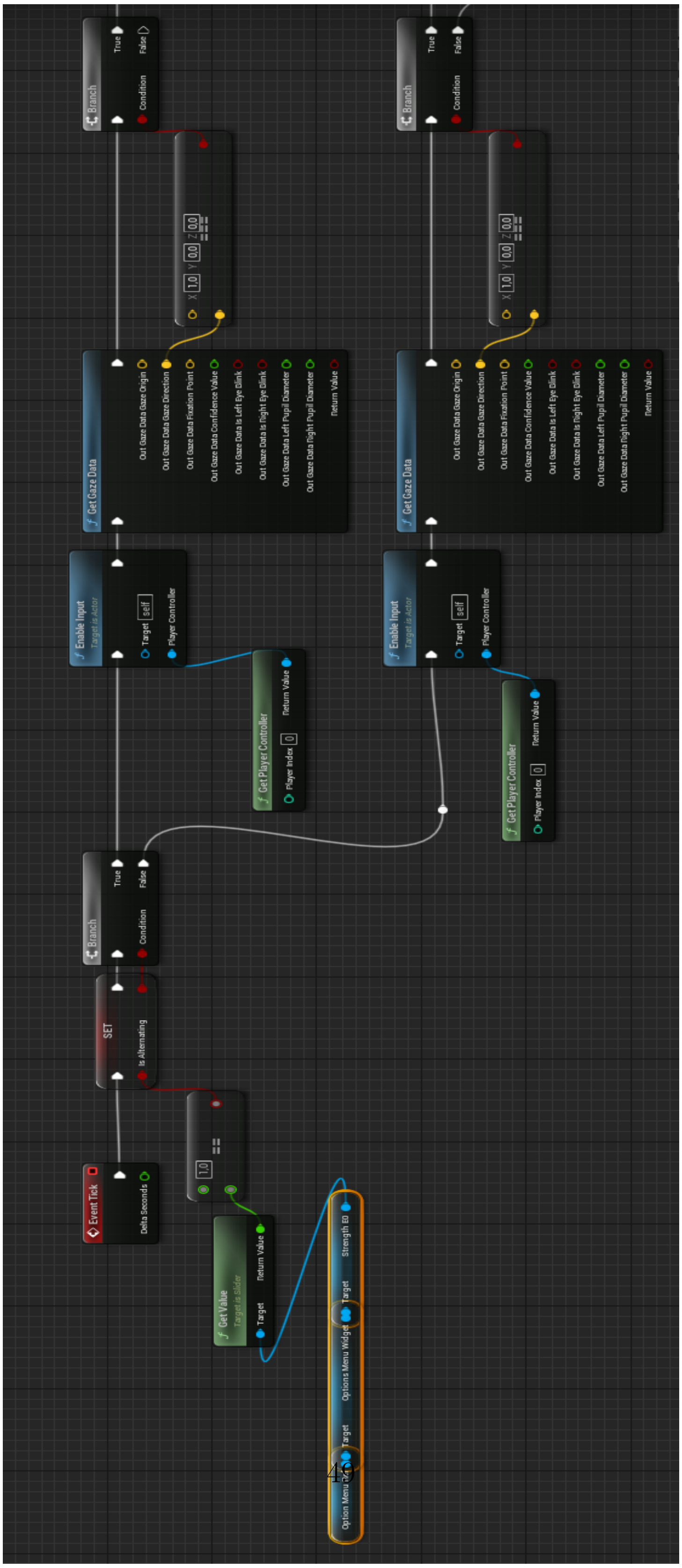


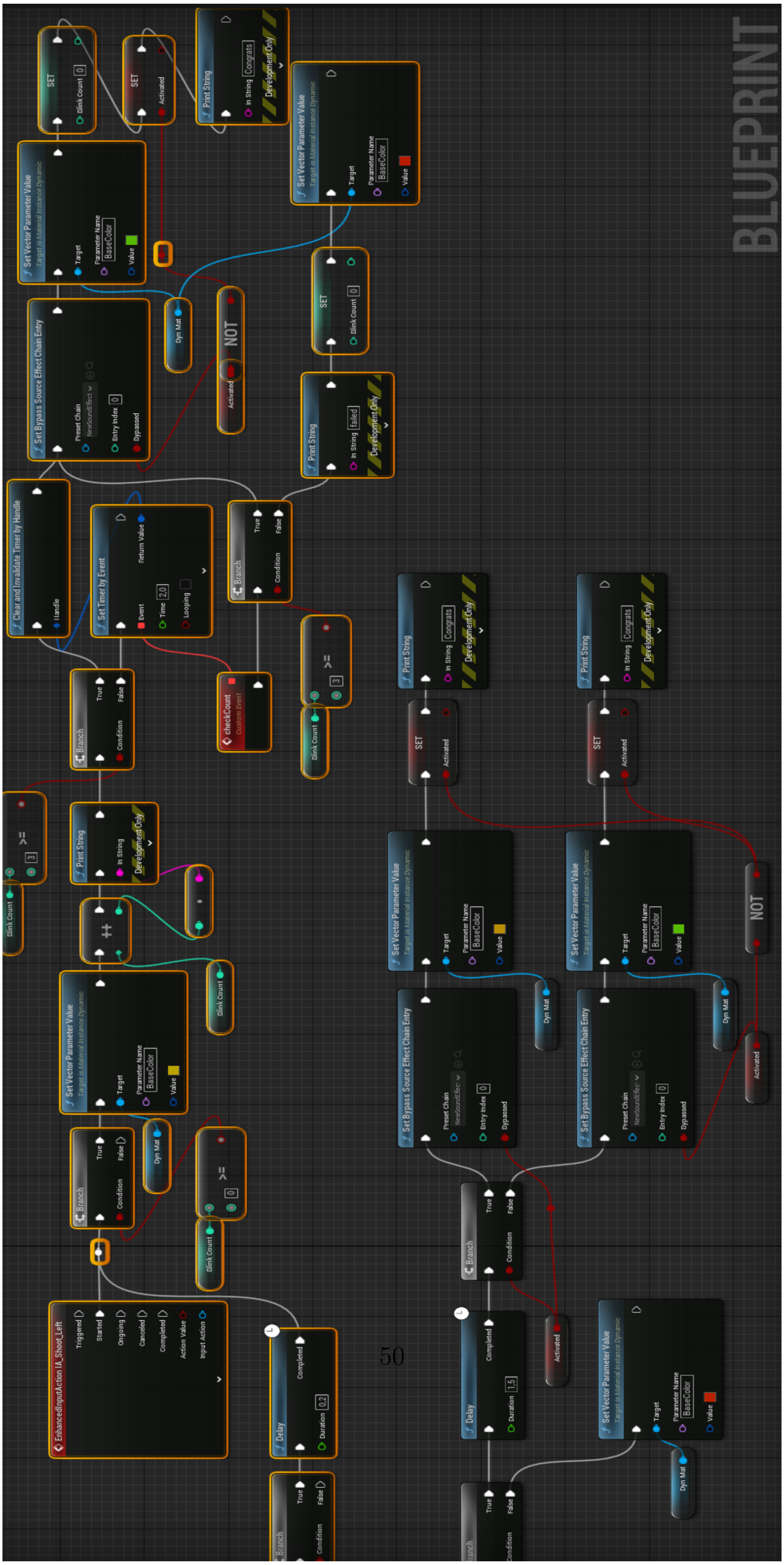

Event BeginPlay
Get Actor Of Class
Actor Class
Options Menu A
Return Value
? Is Valid
Exec
Input Object
Is Valid
Is Not Valid
SET
Option Menu
On Component Begin Overlap (Box)
Overlapped Component
Other Actor
Other Comp
Other Body Index
From Sweep
Sweep Result
Bind Event to Emg Value Updated
Target
Event
CustomEvent
Custom Event
Emg 0
Emg 1
Prosthesis Action
Action Speed
SET
Audio Capture
Adjust Volume
Target is Synth Component
Target
Adjust Volume Duration
0,0
Adjust Volume Level
Fade Curve
Linear
Guitar Ref
Target
Audio Capture
Option Menu
On Component End Overlap (Box)
Overlapped Component
Other Actor
Other Comp
Other Body Index
Unbind Event from Emg Value Updated
Target
Event

A.2 Foot pressure sensor blueprint



A.3 Eye blink recognition blueprint




BLUEPRINT
EnhancedInputAction IA_Shoot_Left
Triggered
Started
Ongoing
Canceled
Completed
Action Value
Input Action
Delay
Completed
Duration 0.2
Branch
Condition
True
False
Dlink Count
>= 0
Dyn Mat
Set Vector Parameter Value
Target is Material Instance Dynamic
Target
Parameter Name BaseColor
Value
++
Print String
In String
Development Only
>= 3
Clear and Invalidate Timer by Handle
Handle
Set Timer by Event
Event
Time 2.0
Looping
Return Value
checkCount
Custom Event
Set Bypass Source Effect Chain Entry
Preset Chain NewSoundEffect
Entry Index 0
Bypassed
NOT
Activated
SET
Dlink Count 0
In String Congrats
In String failed
Duration 1.5

Appendix B

p-value determination python code

```
import scipy.stats as st
import numpy as np
EMG = np.array([12, 13, 17, 18])
foot = np.array([8, 15, 7, 14])
eye = np.array([6, 10, 4, 4])
st.ttest_1samp(EMG-foot,0,alternative="greater")
st.ttest_1samp(EMG-eye,0,alternative="greater")
st.ttest_1samp(foot-eye,0,alternative="greater")
```

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