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DEPARTMENT OF BIOMEDICAL ENGINEERING

PROJECT REPORT

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TITLE Event-Related Potentials for Virtual Reality Interactions

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Abstract

Brain-computer interfaces have been a fascinating technology trend for enabling users to interact with devices in new ways. A class of brain activity called event-related potentials (ERPs), due to their ubiquity an easy reproducubility, have become the most popular signal used in designing electroencephalography (EEG)-based BCIs that give users the ability to control devices and software. For example, ERP-based BCIs have been extensively applied to developing neural prosthesis and communication devices for individuals with amyotrophic lateral sclerosis (ALS). In addition to being applied to accessibility interfaces, ERP-based BCIs have also been used for entertainment applications. Commercial companies such as Neurable have produced EEG headsets that integrated directly with the HTC Vive virtual reality headset. Virtual Reality is another technology that shows great promise commercially as well as in research. Using both these technologies together, prior studies have utilized BCIs for controlling VR, but few have used the most recent generation of VR hardware. We developed a virtual environment for testing different ERP-based BCIs for VR. The virtual environment places participants in a virtual apartment, mimicking an everyday setting. Our choice of ERP was the P300 component of ERP which has been extensively studied and applied to the development of selection interfaces for communication and navigation. To test our environment, We implemented an auditory-P300-based BCI designed to enable participants to select objects in the virtual apartment environment by focusing on sounds associated with the objects. We then pilot tested our paradigm by collecting data from team members as they used our BCI in VR. While we were not able to obtain classification accuracy of ERP activity above chance, we still hope that this work will help jump-start future BCI/VR studies in the lab on how to design virtual reality, and augmented reality experiences to take advantage of ERP-based BCIs.

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Introduction

Virtual Reality (VR) has grown in popularity over the years and has shown to be both a fun platform as well as useful tool for research. Studies have used VR for studying stoke rehabilitation [13], visual processing [8, 9], and treating mental health disorders [6]. Out-of-the-box, VR systems include motion controllers and cameras for motion/positional tracking. Additional products for augmenting the existing VR hardware include haptic suits, omnidirectional treadmills, and additional body trackers. Recently electroencephalography (EEG)-based Brain-computer interfaces (BCI) have also been introduced as a commercially available VR peripheral. Electroencephalography uses electrodes to read voltage levels on the wearer's scalp. This voltage data can be recorded and used to make inferences about what the wearer's cognitive processes. When EEG is utilized as a control signal for BCIs, commonly developers will use the set of brain activity known as that are known as event-related potentials (ERPs). ERPs are measurable responses to a stimuli and there are multiple types and components of ERPs. For example, Steady-State Visually Evoked Potentials (SSVEP), Event-Related Negativity, P300, etc. Each one is correlated with a different type of sensory, motor, or cognitive event. For this study we chose to focus on the P300 component of ERPs. The P300 is correlated with stimulus uncertainty and decision making and is characterized by a positive spike in the EEG recording around 300 ms after stimulus presentation. It's reproducibility and vast repository of literature makes it an ideal control signal.

The P300 response was first documented in 1965 [18] and has been extensively studied over the years [15]. The oddball paradigm is the most popular method for eliciting the P300 ERP. The paradigm involves a stream of regular stimuli that is occasionally interrupted by the presentation of a unique or deviant stimulus. The application of the paradigm to P300 ERP research was made popular by [17]. Previous studies focused on eliciting the P300 response using visual stimuli [2, 4]. Others used auditory stimuli [10, 16]. When comparing the performance of the two, the auditory paradigm does not perform as well as the visual paradigm, however it can still be used reliably [7].

The P300 paradigm has been applied to virtual reality platforms for both environment interaction [1] and immersion measuring [11]. Many studies have participants focus on visual stimuli for P300 elicitation, but purely visual stimuli limits the accessibility of the interface to those with adequate vision. Moreover, these interfaces are gaze-based and lend themselves to visual fatigue by requiring the user to focus persistently. Spatial-Auditory P300 allows a user to select objects in virtual space without having to visually attend to them. Previous studies, such as those by [5, 10, 16] explored the use of the P300 component elicited during spatial audio tasks. Other researchers have compared the usability and workload of 2D auditory P300 and visual P300 applications [10].

For this project, we built a VR environment in which to test selection control schemes based on ERP BCIs. We then implemented an audio-P300-based BCI which uses an audio direction as the discriminating cue in an oddball paradigm.

Motivation

We chose to apply BCIs to virtual reality mainly to explore the process of developing BCIs the interface. EEG-BCI/VR technology presents a fun opportunity to create unique experiences for video games. In addition, to possibly being fun to use, P300 based BCIs have also been used as accessibility solutions for individuals who may not me able to use standard control interfaces. One specific area where they have been applied is providing control interfaces to individuals suffering from amyotrophic lateral sclerosis (ALS) or ”Locked-in Syndrome”. P300-based BCIs have shown to be helpful in the area of providing a means of communication [3, 14, 12]. This style of project was a first for the lab and we hope that it helps to inspire or be used in future work.

Methods

Data Acquisition and Processing

EEG was recorded using a BrainProducts ActiCap Xpress EEG 16-channel dry-electrode cap and V-Amp hardware. EEG was references to the right earlobe and grounded on the left earlobe. A small amount of EEG conductive electrode gel was placed on the reference electrode, ground electrode, and other electrodes to help improve signal quality during recordings. Data was streamed from the EEG cap to the environment using an open source library called, LabStreamingLayer (LSL). During processing the EEG signals were, notch filtered at 60 Hz, decimated by a factor of 4, high-pass filtered at 0.1 Hz and low-pass filtered at 35 Hz, and finally epoched time-locked to the stimulus on the interval -0.2s prior the stimulus and 1.0s after. For audiovisual presentation we used a HTC Vive VR headset and a pair of Beats over-ear headphones.

Figure 1: Pictured are the Brain Products V-Amp/ActiCap Xpress system (left) and HTC virtual reality headset/controllers (right)

VR Apartment Environment

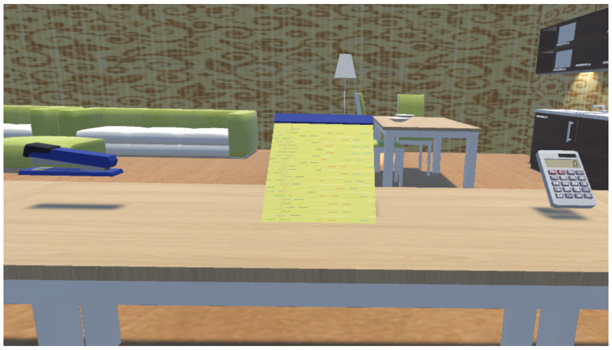


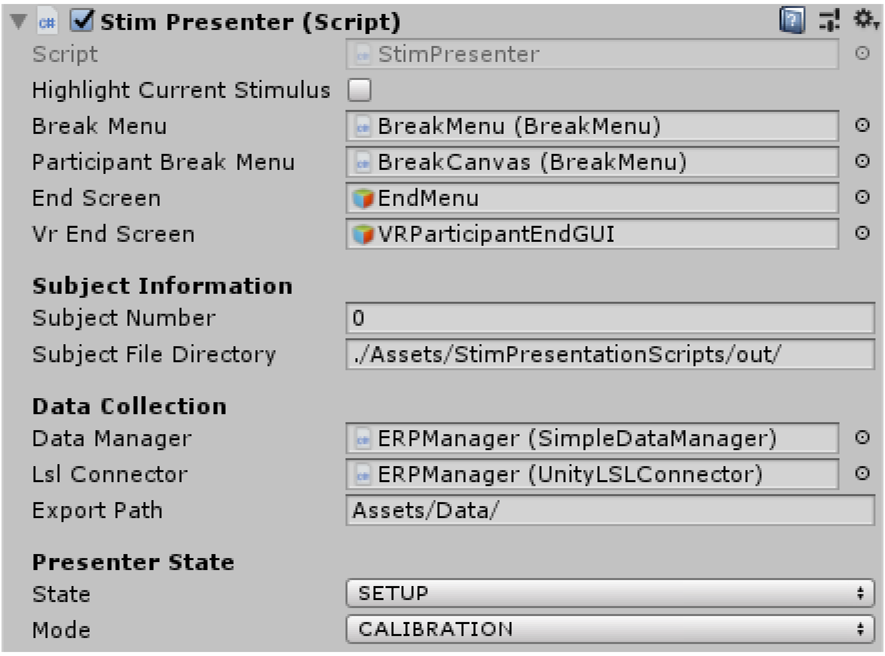
Figure 2: Screenshot of the VR apartment. All 3D models and materials are available for free at the Unity Asset Store under the “Office Supplies Low Poly” pack by Sten Ulfsson and “Big Furniture Pack” by Vertex Studio.

Using the Unity game engine, We developed a VR apartment environment meant to mimic real-life. Unity allowed us to take advantage of the SteamVR plugin and other free asset packages available on their asset store. The game engine is responsible for presenting the stimuli to the participant as well as reading data streamed from the EEG cap, integrating event codes with the data, and finally exporting it for future processing. Communication between the EEG cap and the engine is accomplished with the use of LSL, an open source library for streaming time-series data locally or over a network. We chose to utilize LSL to make our VR environment hardware agnostic, giving experimenters the option to substitute the BrainProducts headset with alternatives such as BioSemi caps or OpenBCI caps.

Implementation Details

All code is available on GitHub at: https://github.com/ShiJbey/AudioERP.

The environment used for pilot testing is contained in the ’Assets/VR/PilotTestSimple.unity’ scene file. The Unity scene is configured to use the SteamVR plugin and an HTC Vive headset. The core of the environment’s functionality is split between a few scripts.

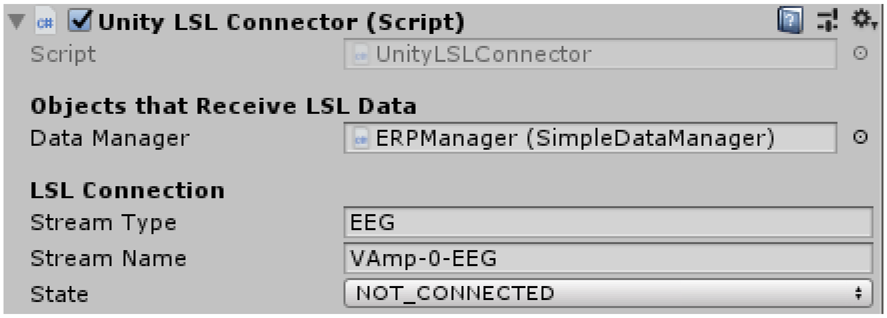


☑ **Stim Presenter (Script)**

Script	StimPresenter
Highlight Current Stimulus	☐
Break Menu	BreakMenu (BreakMenu)
Participant Break Menu	BreakCanvas (BreakMenu)
End Screen	EndMenu
Vr End Screen	VRParticipantEndGUI
Subject Information	
Subject Number	0
Subject File Directory	./Assets/StimPresentationScripts/out/
Data Collection	
Data Manager	ERPManager (SimpleDataManager)
Lsl Connector	ERPManager (UnityLSLConnector)
Export Path	Assets/Data/
Presenter State	
State	SETUP
Mode	CALIBRATION

Figure 3: Stimulus Presenter Script in the Unity editor

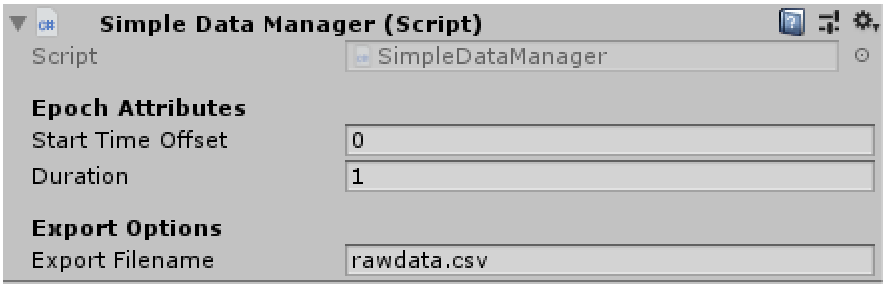
The stimulus presenter script coordinates most of the heavy lifting. It is responsible, first and foremost for stimulus presentation. This includes loading the participant's stimuli file, presenting break menus, and telling the Data Manager when to write data to a file and clear its buffers. Additional parameters such as stimulus onset asynchrony are hidden from the editor, but can be configured within the script. The presenter maintains two states, the first called 'State' can take on the values [SETUP, CUE, PLAY, EXPORT, BREAK, WRITING_DATA]. The second state is 'Mode' which may take on the either of the following two values, [CALIBRATION, LIVE]. The intention of these states was for future expansion when the system could be used to make live classifications on participants recorded EEG. During pilot tests, we only ran the system in calibration mode which was designed to collect data for the specific purpose of training a machine learning classifier to recognize the user's p300 ERP..


Unity LSL Connector (Script)
Script: UnityLSLConnector

Objects that Receive LSL Data
Data Manager: ERPManager (SimpleDataManager)

LSL Connection
Stream Type: EEG
Stream Name: VAmp-0-EEG
State: NOT_CONNECTED

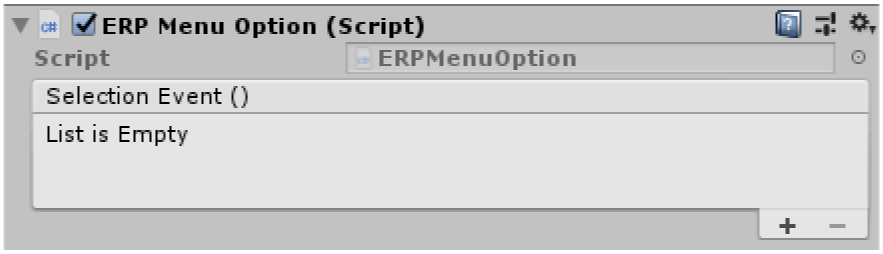
Figure 4: LSL Connection Script in the Unity editor
The LSL Connector's purpose was to find an LSL stream on the network that had a matching type and name. When a matching stream is found, the connector changes its state from NOT_CONNECTED to CONNECTED. Finally, this script requires a reference to the Data Manager so that data can be continuously stored in the Data Manager's data buffer. The GUI in the pilot test scene prevents the experiment from starting if the LSL Connector is not connected to an active stream.


Simple Data Manager (Script)
Script: SimpleDataManager

Epoch Attributes
Start Time Offset: 0
Duration: 1

Export Options
Export Filename: rawdata.csv

Figure 5: Data Manager Script in the Unity editor
The Data Manager is responsible for storing EEG data given to it from the LSL stream and exporting it to a CSV file. Due to the fact that LSL Connector operates in a separate thread, access to the Data Manager's buffer is protected by a mutex.



☑ ERP Menu Option (Script)

Script ERPMenuOption

Selection Event ()

List is Empty

Figure 6: ERP Menu Option Script in the Unity editor

Finally, the ERP Menu Option Script is attached to all objects that we want to have as options to be selected using the users P300 ERP response. It has one public variable which is just a list of callback functions to execute when the object is selected. All Menu options should be places as child objects to the Stim Presenter.

Stimulus Presentation

Participants were asked to sit for a single EEG data collection session where they listened to a pre-generated pseudo-random-ordered serial stream of 200ms 500Hz beeps being played through stereo headphones with a stimulus onset asynchrony of 300ms. Sounds were spatialized by the Unity game engine to give them the illusion of originating from different directions in virtual space (left, right, middle).

Stimulus presentation was comprised of 15 sequences of 3 blocks of 45 trials see [Figure 7]. For this experiment we define a trial as a single sound presentation from either the left, right, or middle. Each participant had a different order of 15 sequences. Each sequence is 3 blocks, 1 block for each sound direction in pseudo-random order. Each block was 45 pseudo-randomly ordered trials, with 33% of trials belonging to the target sound direction/object. The goal was to collect a total of 2025 trials across all blocks, with at least 675 of these being target trials and the remaining being non-target trials.

The stimuli order for each participant was generated using a Python script that ensured that all participants experienced a different ordering of conditions.

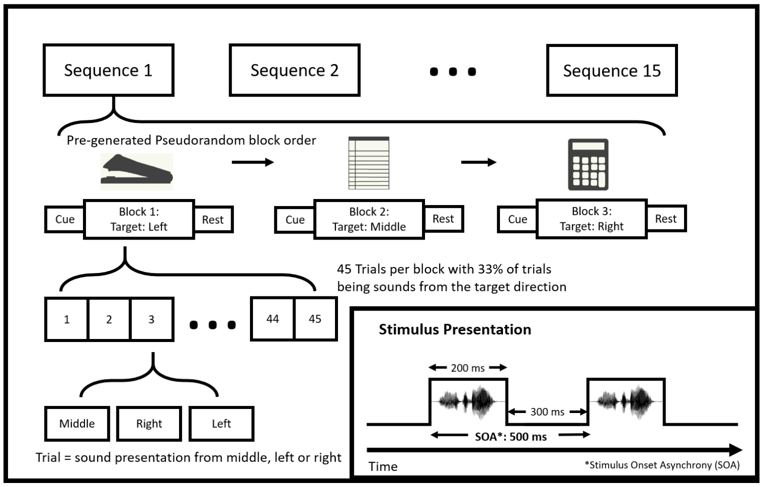


Figure 7: Stimulus presentation structure. Participants were shown a total of 2025 stimulus trials (60% being target-trials). Data collection too about 45 minutes.

BCI Paradigm

Our paradigm was an p300 BCI which used a auditory oddball paradigm to elicit the p300 response. It requires participants to distinguish between a cued target sound and non-target sounds, using sound direction as the discriminating characteristic. Each beep was associated with a different object in the virtual environment and the target object/sound is the object to be selected. In our environment, participants only three objects are available for selection. So, the task of identifying a single type of beep, for example left beeps from a set of left, right, and middle beeps, established the oddball paradigm with the target class has probability 0.33.

Blocks began with the participant being cued with a target object/sound direction (left, middle, or right). The cue was indicated by highlighting the target object and playing its associated sound three times. After the cue, there is a brief pause before the sound stream begins. The participant's task is to listen to the stream of sounds and count the number of times that a sound is presented from the cued target object. This number is reported to the experimenter at the end of the block. Participant then start a new count for the following block. The counting task is used to help maintain participants' focus which has been shown to help strengthen the p300. A break screen appears at the end of each block indicating a rest period. After taking at least a 5-second break, participants are asked if they wish to continue with data collection. When they are ready, they press a button to resume the experiment and start the next block began. This cycle is repeated until all blocks were complete for the current sequence. At the end of a sequence, participants were asked to take at least a 10-second break before continuing with the next sequence.

Figure 8: VR Break Menu
The environment features built-in break menus, with configurable wait time for ensuring participants take breaks of proper length. Participants used the Vive controller to press the resume button when they were ready to continue with data collection

Pilot Testing

We pilot tested the system using three members in the lab. For pilot tests, participants sat for a 45 minute data collection session. For data analysis we chose to use 8 electrodes focused near the parietal region of Brain where the p300 has shown to be strongest. We visualized the average wave forms of the epoched EEG signals and noticed that only the left condition had captured a noticeable P300 ERP. Furthermore, we attempted to train a Support Vector Machine classifier to be able to classify between target (P300 present) and non-target (P300 not present) epochs. The SVM was trained on epochs which were averages of five epochs belonging to the same condition. Averaging is used to help reduce recording noise and make the P300 component more prominent. After running a 10-fold cross validation with the data, the system could not achieve above chance accuracy when classifying conditions.

Figure 9: Participant sitting for pilot test.

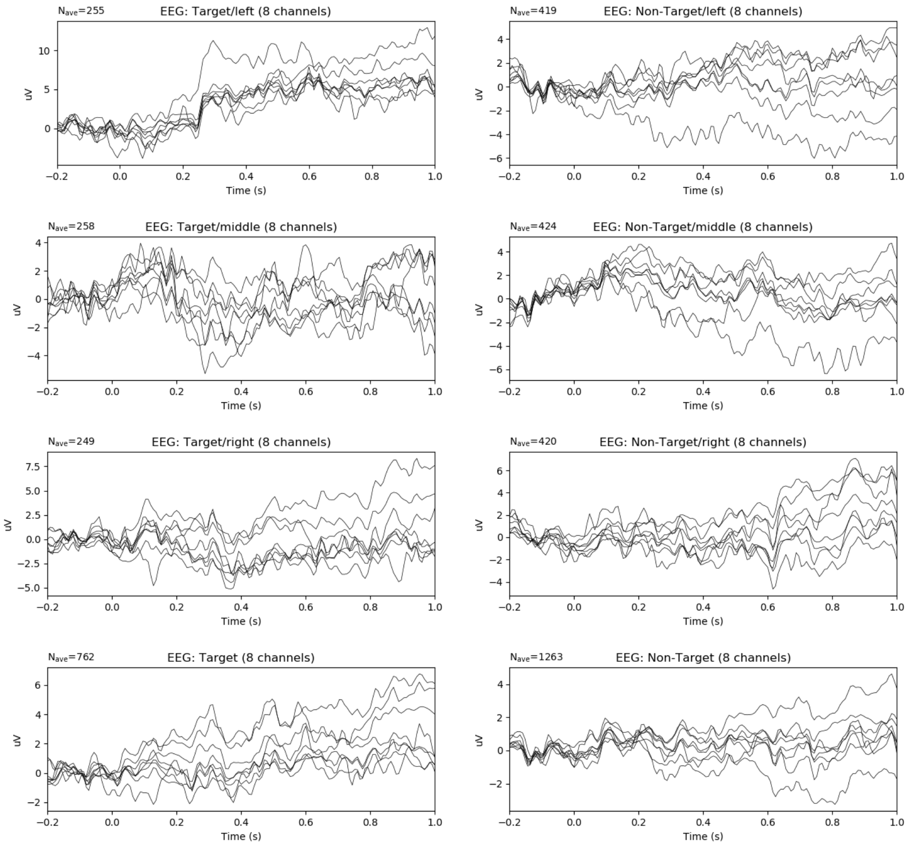


Figure 10: Plots of EEG average voltage of epochs of a pilot test. The chosen Channels were Cz, Cp1, P3, Pz, Cpz, Cp2, P4, Poz] 10-20 positions. The P300 ERP can be seen in the 'Target/Left' plot as the positive increase in the EEG at 0.3 seconds.

Discussion

This project helped to lay the ground work for the lab's potential future studies involving VR and EEG. Previous studies proved that audio-spatial P300 BCIs were viable and this project served to translate that work to the newest generation of VR hardware. The lab now has an environment for testing ERP BCIs in VR. Unfortunately, the system did not produce clean ERP measurements and thus diminished classifier performance when analyzing data. Some users differentiating sound directions difficult, so we believe that the use of Customized head-related transfer functions (HRTFs) could have helped participants better differentiate sounds. Also, using a Wet-electrode system instead of a dry one could have reduced the amount of noise accumulated in recordings. Future work could look into these concerns to see if the help with performance and system usability.

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