BrainBraille fMRI Training System: Report

CS 7470/CS 4605: Mobile & Ubiquitous Computing

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ABSTRACT

Many people either develop or are born with conditions such as ALS [4] that inhibit them from communicating using their natural speech. The process can start off with severe motor dispairment and progress to a speech impairment [5]. People who develop such conditions can watch the world move around them but are unable to move or communicate. The obstacle of not knowing how to communicate while in this locked-up condition can be overcome with BrainBraille. The BrainBraille approach is a BCI approach which maps the tensing and relaxing of six different body parts to the BrainBraille Alphabet that has been created using patterns found in the motor cortex [1]. For context, participants performed tasks by tensing up six different body parts and the Blood-oxygen-level-dependent (BOLD) signal patterns in the motor cortex could be monitored using an fMRI. These signal patterns were then matched to twenty-seven Braille-like characters [1]. During the course of this semester, we focused on developing a wearable prototype, using virtual reality and motion magnification libraries. The combination of these components enabled us to create a Minimum Viable Product (MVP) that could be utilized to prepare users for an fMRI and actively learn the BrainBraille alphabet.

Keywords

BrainBraille, fMRI, Braille, Typing, Motor Impairment, Pose Estimation

INTRODUCTION

The objective of this project was to prototype a BrainBraille-based learning and training system that would prepare users for an fMRI environment . This training system allows users to be properly prepared to participate in a fMRI where they're able to perform BrainBraille with as little head movement as possible. In order to accomplish this goal, our team focused on two components. One, developing and testing a VR system that mimics an MRI environment. For this, we ensured that we mimicked the sense of claustrophobia that MRI environments are known to invoke in patients and limited the patient's head movement within the VR environment itself. To create this environment, we made a WebVR version using a website named Glitch then showed this through an actual VR headset. Two, determining and implementing the best method to monitor vibrations, which ultimately ended up being OpenPose. The examiner has to be able to tell if the participant is conducting BrainBraille properly. Therefore, using OpenPose to highlight the movements of the key points on the human body, feet, hands, and face will assist the examiner in determining whether or not the user is making the correct movements for that particular BrainBraille character. Because of its previous use in this area, as well as the fact that BrainBraille movements are not full motions but rather the relaxing and tensing of muscles, we had to pivot a few different times until we were able to successfully implement an approach to emphasize these movements that was not computationally expensive. After numerous hours of testing the two components individually and together, we finally finished creating a working prototype.

BACKGROUND

Passive Haptic Learning (PHL) is the acquisition of sensorimotor skills without active attention to learning [2]. One method is to "teach" motor skills using vibration cues delivered by a wearable, tactile interface while the user is focusing on another, primary task [3]. In a study containing 16 participants, users demonstrated significantly reduced error typing a phrase in Braille after receiving passive instruction versus control (32.85% average decline in error vs. 2.73% increase in error). PHL users were also able to recognize and read more Braille letters from the phrase (72.5% vs. 22.4%). In a second study, containing 8 participants thus far, the Braille alphabet is passively taught over four sessions. Typing error reductions in participants receiving PHL were more rapid and consistent, with 75% of PHL vs. 0% of control users reaching zero typing error. By the end of the study, PHL participants were also able to recognize and read 93.3% of all Braille alphabet letters. These results suggest that Passive Haptic instruction facilitated by wearable computers may be a feasible method of teaching Braille typing and reading. The wearable, tactile interface used to deliver vibration stimuli is in the form of a pair of gloves. The gloves are fingerless for optimal fit on different size hands, enabling the motors to rest flush near the base knuckle of each finger. Each motor is secured to the stretchy glove layer using adhesive and is located on the back of the hand (dorsal, non-palm-side) inside the glove. These gloves utilize Eccentric Rotating Mass (ERM) vibration motors (Precision Microdrives model #308-100) and are driven High or left floating through a Darlington Array chip attached to an Arduino Nano with buffered circuitry. [9]. Prior research on PHL has shown that PHL users can acquire motor skills simply by receiving tactile stimulation while no perceived attention is given to learning. Seim e.t. Al showed this by creating a curriculum dedicated to teaching users two-handed chord skills via Braille typing. In the study, users are taught two phrases under varying conditions and their learning processes are examined. The goal of this study was to demonstrate the internal validity of passive teaching as well as examine the best method of learning for users - specifically whether one hand or both hands together was best [6]. Following this study, the Mobile Music Touch project focused on passively teaching a key pattern with PHL gloves. Fingerless gloves are embedded with one vibration motor per finger. Type training software records the user’s data and they type using two BAT InfoGrip BAT keyboards that consist only of letters A-H, space, and enter. PHL enables users to learn the idea of “muscle memory” through vibration stimuli without devoting attention to the actual stimulus itself. This study shows that PHL can be used for more complex skills and that understanding can be taught through wearable, tactile devices - especially when visual feedback is available [6]. Seim et al. demonstrate in another study that passive haptic learning can be used to enable users to understand the text through vibrotactile patterns in the form of skin-reading. However, it should be noted that this is an expensive method in terms of time and resources required. Thus, this study demonstrates the efficacy of PHL in training users to be able to perform skin-reading [8]. In another study, subjects were asked to make visual matches to individual braille characters or named two-letter braille words. Tactile examination of braille was either active or passive. Active touch yielded superior performance to all passive conditions, with static presentations producing the poorest performance. Naive subjects were very poor at reading simple braille words with passive touch, but active exploration aided word identification. We hope to utilize Passive Haptic Learning with Virtual Reality (VR) Headsets. VR is experiential. A spatial multi-sensory environment is inhabited, and participants are both physically and perceptually involved in this experience. VR’s biggest advantage is that this environment allows for natural interaction with information. The experience is shared. While a personal computer is designed for solitary operation, virtual worlds can be utilized in both individual and group contexts. Networked VR allows for multiple participants to interact simultaneously in the same audiovisual environment, sharing control naturally while conversing with augmented capability. Time, scale, and physics can all be controlled, enabling VR to be tailored specifically to individuals. Teachers can represent information in forms that are most compatible with a student's particular learning style, selecting interactivity options that match student performance characteristics [9].

Active learning keeps the learner in the forefront of the learning process where they are given the opportunity to learn the necessary skills effectively. Engaging in this type of learning style forces the student to think about how they are using those ideas [11]. It also keeps the student mentally and physically active in their learning without having to deal with rapid memorization. The difference between active and passive learning has to do with students learning by synthesizing the information versus having to memorize [10].

ACCOMPLISHMENTS

Over the duration of the project, we have successfully created two independent components that aids in actively learning how to perform short words using the BrainBraille alphabet while it felt like being in an actual fMRI.

Deviations From Previous Approach

Our biggest pivot was from PHL to Active Learning. The biggest difference between the two, as detailed earlier, is that Active Learning requires less memorization. Because there are several characters in BrainBraille (one corresponding to each letter in the alphabet), we believed it would be overwhelming for patients to have to learn all of these characters in a short amount of time, especially for those who are unable to communicate properly. Thus, we made the switch to Active Learning.

For the movement magnification we ended up using OpenPose, but we didn't start there. We started with Eulerian Video Magnification (EVM). EVM is a technique that applies spatial decomposition, temporal filtering, and signal amplification to amplify subtle movements. We were able to get EVM to run on video files, but we ran into multiple issues. First, we weren't able to segment EVM into enough regions for each of the body parts that would be moved in accordance with its BrainBraille character. Additionally, EVM was too computationally expensive to run on live video. We then switched over to Optical Flow, which essentially allows one to see the movement of velocity vectors between frames. This however turned out to also be too computationally expensive. From there, we tried a different approach using surface-level electrodes that could be attached to the skin, but this turned out to not be feasible as well because way too many electrodes were required and it would take too much time to set up and receive and analyze the data. We then settled on OpenPose, which allows you to more clearly view the movements of various body parts based on clearly color marked key points on the body, hands, face, and feet. The only concern here is the inability to see tongue movements which is one out of the six regions of the body that is included in the BrainBraille alphabet.

Simultaneously, the virtual reality portion was being worked on which we started by writing code in a website called Glitch. This website helped us with a base for creating a virtual reality experience since we were able to do it on the web using A-Frame before showing it on an actual headset. The code is written in HTML but the essential part was using a web framework, A-Frame, on top of HTML. A-Frame allowed us to make full use of positional tracking and is supported by most VR headsets. The name of the headset we used was called BNext VR Headset. How the BNext infrastructure works is by putting a smartphone into the slide out tray and then whatever is playing in VR mode on the phone can properly be seen when the headset is on. A limitation for using this headset is the holder can only fit a phone screen size up to 6 inches. To show our MRI simulation project that was made on Glitch, we obtained the live site link of our project and put it in on a phone's browser. On the page, there is an AR and VR mode option which determines the mode of experience. Since we want a VR experience we switched this mode on and what it did was display the project in a binocular view showing a different angle of the image for each eye.

We initially wanted to have the training system set up so the user is laying down as they would in a real fMRI. However, the VR component side of it was producing many challenges in getting the frame to be where it should be when the user is laying horizontal as the starting position. Thinking it was an issue to do with the type of headset we were using, we tried to set it up on Meta Quest Oculus Rift in hopes that it would allow us to redetermine the center. Unfortunately, it was quick to discover that the Oculus Rift didn't have a way of supporting the link properly. Therefore, for testing purposes we allowed the users to sit in a chair and perform BrainBraille.

Testing

Once the two components were ready, we positioned a wireless camera to face directly at the chair the user sat on. The camera view could be seen live on the examiner's laptop. Users sat on the chair with the BNext VR headset on and the examiner guided them until they were virtually inside the MRI machine. At this point, the user could see a sequence of images leading them through each BrainBraille movement for each letter in the proposed word. While the examiner examined if each one was done properly through the live camera feed.

RESULTS

We tested our training system on a population of 9 Georgia Tech undergraduate students. We received feedback of the training system feeling claustrophobic and limiting due to having to keep their heads still. These are positive results since our main objective was to get it to feel as close to a real fMRI as possible with factors the participants pointed out. From the examiner point of view, we attempted to make it easy to be able to tell which letter was being signaled. We received generally positive reviews, but we also received feedback that said it was easy to tell which muscles were being moved, but hard to translate that into a specific letter. In future versions, we would plan on displaying the exact letter the tester is signaling with their muscles. The accuracy levels for each word we had the user perform in BrainBraille was high and we expected this to be since the body parts needed to be moved are actively being shown.

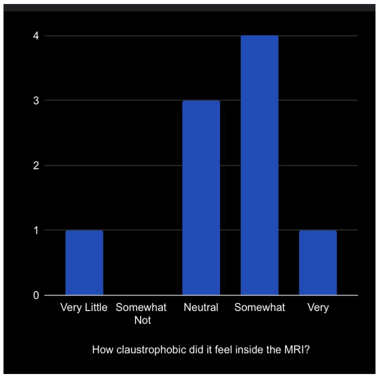

Figure 1: Sensation of Claustrophobia

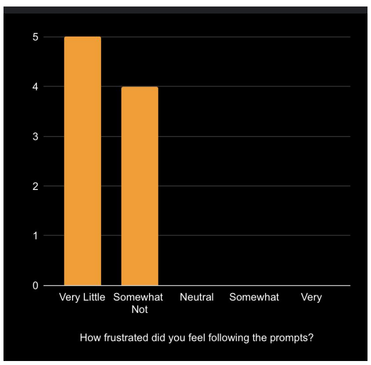

Figure 2: Frustration Using Training System

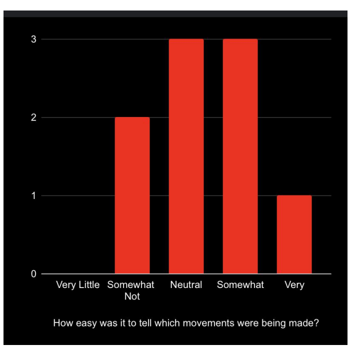

Figure 3: Ease of Motion Recognition

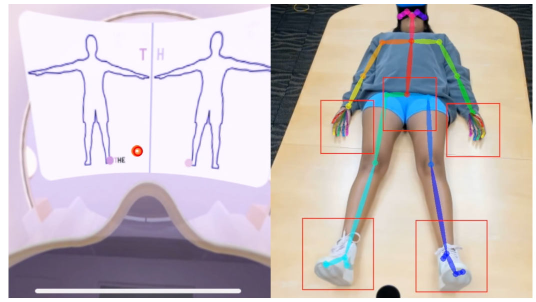

Figure 4: Examiner's View when Testing

CONCLUSION/REFLECTION

From our results, it's clear that our product is a successful MVP in terms of enabling the examiner to clearly see which body parts are being moved. As explained throughout this paper, this helps the examiners see whether or not the patient is performing the movements that correspond to the BrainBraille character that is presented to the patient via the VR environment.

However, because this is an MVP, it is merely a stepping stone. The ultimate goal is to create a universal BrainBraille system that patients with any kind of fine motor disability can successfully use to prepare for an fMRI environment. The first group of patients that needs to be accounted for is that which encompasses those with poor and zero vision. Our current system relies on the patient being able to see, which is not always going to be the case so we need to either build an alternate system for that group or build additional options upon our existing product.

We also did not get the chance to test our product on people with fine motor disabilities. Thus, we aren't sure how effective our product would be with more subtle movements. Additionally, in the event that a patient is unable to make a particular movement independently (meaning they have to make other movements in order to actually move that specific body part), we are not sure that the correct movements would be clear to the examiner, so this is something that we would have to fix as well.

As such, if we had the time to go back and build this product from scratch again, we would definitely allocate more time towards testing. We would also follow more of a fast iterative approach. In particular, on the movement magnification side, we spent too much time trying to get EVM and Optical Flow to work on live video when we should've been moving onto other ideas such as OpenPose faster.

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