Navigation Path Differences for Dichotic Listening BCI in Virtual Environments

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ABSTRACT

Our research is focused on the initial exploration of training a Brain Computer Interface (BCI) by using audio cues to navigate a virtual environment, instead of motor imagery. We have designed our BCI training and navigation to use audio cues that adhere to the dichotic listening (DL) mechanism so that users have an active choice for interaction or giving commands. We have implemented our Dichotic Listening BCI in a Virtual Environment so that it can be used to train users with disabilities to apply those skills for a BCI to control a real-world assisted locomotive device or to simply navigate within the virtual environment. We hypothesized that the lateralization of the brain's response to music and speech will enhance the classification of a BCI. Unlike previous attempts in using the oddball paradigm, our results show that audio cues can be used simultaneously to elicit distinct EEG signals for BCI while still enabling an active choice for the user. We evaluated users' performance to actively input navigation tasks. Dichotic Listening BCI performs slightly better than Motor Imagery based BCI. In addition navigation paths reveal participants having more navigation control when using Dichotic Listening.

Keywords: Virtual Environments; Navigation; Brain-Computer Interface; speech; music; Dichotic Listening; simultaneous stimuli; Users with Disabilities; Navigation Paths.

Index Terms: J.1.3.[Human Computer Interaction (HCI)]:Interaction Devices—Sound Based Input/Output; J.1.2.[Human Computer Interaction (HCI)]:Interaction Paradigms—Virtual Reality; J.1.1.[Human Computer Interaction (HCI)]: HCI Design and Evaluation Methods—User Studies;

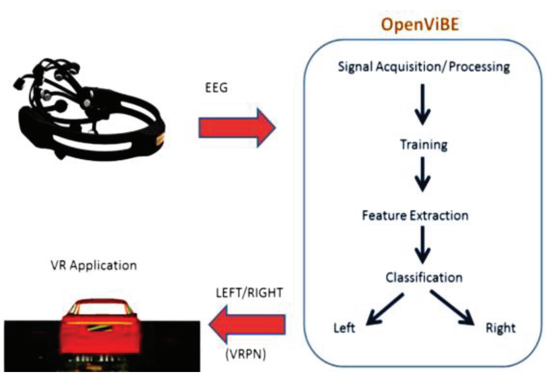

Figure 1: Process for converting data acquisition from BCI to VR application for navigation

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1 INTRODUCTION AND MOTIVATION

There is a motivation to assist people who cannot use their hands or feet well due to various medical conditions, paralysis, injuries or other physical limitations. A Brain Computer Interface can facilitate new ways of interaction. Brain Computer Interface (BCI) is a device that reads electroencephalographic (EEG) signals from the brain, interprets them, and then converts those signals into input commands to a computer. In addition not only can a BCI serve as an input device to initiating commands to the computer, but could also serve as a mechanism to control a physical locomotive device, such as a motorized wheelchair. A Virtual Environment (VE) can assist users with training in using the BCI for navigation. The four components of a BCI system are: signal acquisition from the brain's electrical activity, signal processing, feature extraction and classification, and an application interface for the interaction between the user and these components [8]. Training of BCI requires EEG signals to be classified based on similar features, and then later used as input commands to a computer. One problem with classification accuracy is extraction of distinct EEG signals for each input command. A majority of the BCI systems developed have used visual stimuli to activate a distinct EEG signal, for example the user has to either train the BCI by either looking at a directional cue and imagine limb movements, or by gazing a flickering stimuli. Motor imagery based BCIs have been used in a number of virtual reality applications to explore a virtual bar or to navigate on a virtual street, or to steer a virtual car [2,8,9]. Motor imagery based BCI elicits distinct EEG signals produced during imagination of arm movements to provide commands to a computer [8]. For a person using a motor imagery BCI, it is hard to be consistent with the imagination of arm movements. Moreover, motor imagery BCI requires lengthy training sessions.

Our research is focused on exploring an audio-stimulus based BCI by using dichotic listening. A dichotic listening phenomena occurs when two different auditory stimuli are presented simultaneously and the user may be able to selectively focus on one. Prior psychology research has shown that dichotic listening situation is able to elicit distinct EEG signals in the brain [4,6,11]. Other studies have explored the possibility of auditory BCI based on selective attention to audio stimuli [5,6,7], however none adequately provide the user with active choice for computer input. Most closely related, Kim et. al presented classification results of selective attention, where two different frequency beats were played separately in each ear to generate Auditory Steady State Responses (ASSRs) [7]. This study only looked at classification results for the left and right ears as audio stimulus played consecutively. They instructed the user which ear to pay attention through audio beeps, also known as an oddball paradigm.

Our research is significantly different in that we present an evaluation of a dichotic listening BCI classification when simultaneous and continuous stimuli are played in both ears to generate distinct EEG signals facilitating user-directed control, where classification may be more difficult due to the added noise. Also, our work significantly differs in our implementation of the virtual environment, where we present a more realistic interaction scenario and have evaluated the performance of the user to actively input or choose which to select or pay attention to one stimulus over the other, as we have done in our study. We use music and speech stimuli, because they have been previously shown to have physical ear advantages [3,12] and may be more comfortable than beeps. For our prototype, we implemented a Dichotic Listening based BCI for navigation in a Virtual Environment. We present an evaluation of the classification for a Dichotic Listening based BCI and users' performance in actively choosing directions during a navigation task. We compared results to using Motor Imagery based BCI. We hypothesized that Dichotic Listening BCI would result in better classification and navigation because it is based on more consistent stimulus-response rather than imagination.

2 Related Work

Motor Imagery has been used to navigate a virtual street, or to steer a virtual car, or to explore a virtual bar [8,9,13]. SSVEP BCI has been used to control the balance of a virtual character or to navigate in a virtual cabin [8]. Similarly, a P300 BCI has been used to control a home environment-opening/closing doors, and switching TV channels [4]. Studies by Guo et. al used the oddball paradigm to design an auditory BCI [1]. Oddball paradigm is a technique of eliciting a distinct EEG signal by asking a user to react to a specific stimulus hidden in a series of random stimuli (either auditory or visual). Gao et al. conducted a similar study using a virtual sound field [2]. In Hill et al.'s studies, a BCI was trained by having a participant look at a directional arrow and respectively focus her attention on either of the two auditory stimuli coming from the left or right [5]. There have been relatively few studies related to auditory BCI. Guo et al. used the oddball paradigm to design an auditory BCI [1]. The participants in this study were asked to distinguish the laterality of the audio (either coming from left or right ear) or discriminate the gender of the speaker among a random sequence of eight spoken Chinese digits (from 1-8). Various dichotic listening studies, not using BCI, have shown that focusing ones attention to either of the stimuli activates certain areas of the brain [3,6,12]. Clemens et. al.'s study examined ERAN and ELAN affects by irregular chords and violations in linguistic context [11].

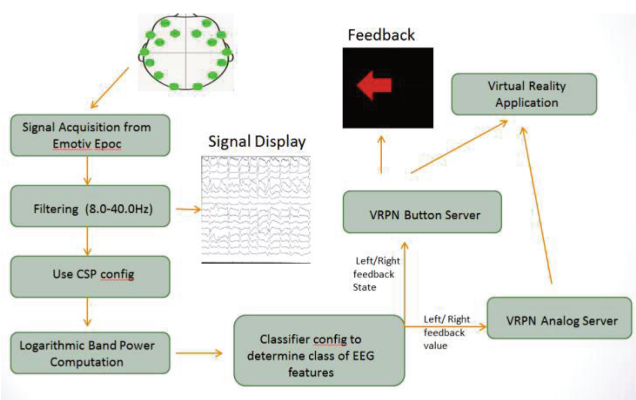

Figure 2: . Process during live EEG Aquisition

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3 Approach

Our research is focused on exploring the navigation of a virtual environment using a BCI with audio cues, instead of motor imagery, that adhere to the dichotic listening (DL) mechanism so that users have an active choice in issuing commands. Music processing is shown to have a Left Ear Advantage (REA) and speech processing is shown to have a Right Ear Advantage (LEA) [3,12]. We chose stimulus based on these previous results. We used Ogre3D to render a maze designed in 3DSMax. OpenVibe and VRPN communicated between Emotiv Headset and the VE. The virtual environment was designed such that participants in the study were to navigate a uni-directional maze as quickly and as accurately avoiding obstacles as possible. The uni-directional maze was designed so that users could actively choose their navigation path, but in such a way that we could evaluate the correctness of the interpretation of the BCI to which direction the participants chose. Participants move a virtual car at a constant speed forward, to reduce noise in the EEG signals.

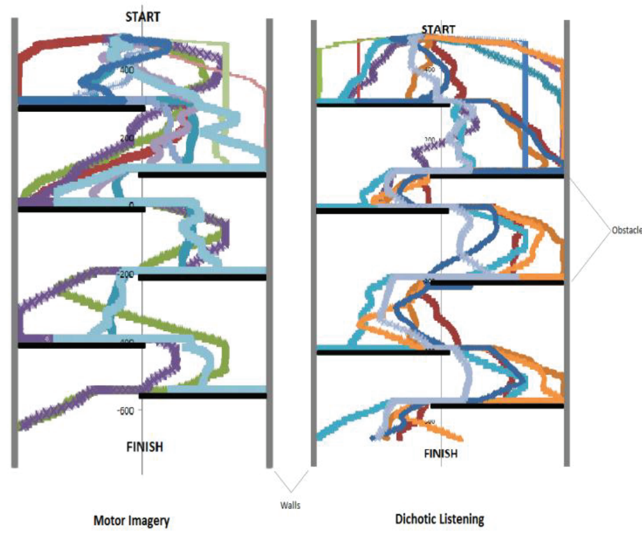

Figure 3: Path Visualization Differentiated by BCI Type.

4 Results and Discussion

Our study was a between subjects design, that included 12 novice participants, with ages ranging from 21 to 31 (Mean = 25.00; SD = 2.40), took part in the study. Out of these participants, there were seven males and five females. Out of these 12 participants, five participants used the dichotic listening based BCI and seven used the motor imagery based BCI. Each participant received one session of training of about 5 minutes for each condition and then participated in a practice session, where the BCI input was trained and classified, which user participation lasts for about 20-30 minutes and post-processing lasts about 10-20 minutes. We were interested in finding out if a participant who used dichotic listening could perform the navigation with minimal training and less/no knowledge of the system. We did not use a within subjects study design for the reason that lengthy classification session limits how many conditions can be performed without fatigue becoming a factor. Results of the classifier performance yielded 78.40% (SD=1.45) for Dichotic Listening based BCI navigation which was higher than 75.59% (SD=1.86) for Motor Imagery based BCI for navigation. We measured accuracy in navigation by counting each correct or incorrect direction the user took. A direction was correct if it was the same the one pointed by the respective directional arrow in the VE. We also measured completion times for navigation. Out of seven motor imagery participants, one finished the task. Out of five dichotic listening participants, three finished the task. The completion times for dichotic listening (M=403.60 sec, SD=202.07) was better than that for motor imagery (M=550.58s, SD=142.09). The high standard deviation may be attributed to the fact that participants were given 10 minutes to complete the task, and if not, then the task was stopped. The accuracy in navigation for dichotic listening (M=74.87%, SD=23.02) was also better than that for motor imagery (M=65.30%, SD=31.08). We also plotted the navigation path for each condition which also visually confirmed that dichotic listening users navigated more efficiently around obstacles and lost control less against the boundary walls than motor imagery users. Although differences in the results of accuracy, completion times, and subjective ratings were not significant, we reported those differences because we believe there is a trend and cannot make finalized conclusions that they are not significantly different due to the low number of participants. We need to run more participants in order to conclude the results. Also, we intend to conduct a more long term study where we hypothesize that Dichotic Listening technique will produce more consistent accuracy results without the need for retraining. We have collected some pilot data in this regard and it looks promising, though we cannot make any conclusions as of yet.

Additionally plots of the navigation paths were made to illustrate the path differences between the two types of BCI training. Half of the paths were mirror-images, so we reversed them in order to plot all trials overlaid. From the plots, not all participants in motor imagery condition finished the task. The participants had a set time to complete the task (10 minutes) and the program exited once that time was up. It is visible that two ceased at the third obstacle and the remaining almost finished but did not get past the last obstacle. It is evident that with the motor imagery condition that more participants spent time along the wall and dragging along the obstacles back and forth in attempt to pass. A small nudge left or right, may be enough for participants to pass the obstacle. However if participants end up against the wall, they may need to make several attempts to control the car in the opposite direction. This occurs because the system may misinterpret the brain signal and cause them to move against the wall again. There is some of that in the Dichotic Listening technique, but not to the extent to where it slowed the participants down significantly not to finish, as in motor imagery. In future work, we would like to explore this result further.

Subjective feedback provided can be summarized that most participants reported frustration during the navigation task when they could not move the car in the direction they wanted to, but dichotic listening was favored over motor imagery. Participants who used the dichotic listening BCI found it comfortable to concentrate on the audio stimulus. However, the participants who used the motor imagery BCI found it difficult to be consistent with the imagination of arm movements. These results are a clue to where dichotic listening may outperform motor imagery. We plan to conduct a long term study where, only one training session will be given and participants will return for repeat performance sessions. We believe that over time, motor imagery performance will decline without subsequent training, and dichotic listening will provide consistent performance without additional training sessions.

5 Conclusion

Initial results show that the classifier for the Dichotic Listening is slightly higher compared with Motor Imagery. Our initial prototype and pilot study have provided potential to the use of dichotic listening as a user-directed navigation method. We have applied the technique in a virtual environment, which can be used as a training application for people who can use the BCI as a way to control assistive locomotive devices in the real world.

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