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A COMPARISON OF NEURAL ACTIVITY FOR PERIPERSONAL AND
EXTRAPERSONAL VIEWING IN REAL AND VIRTUAL ENVIRONMENTS

By:
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A thesis to the faculty of The University of Mississippi in partial fulfillment of the requirements
of the Sally McDonnell Barksdale Honors College

Oxford
May 2020

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ABSTRACT

This study involved a series of tests comparing the similarities and differences in neural activity at a subject's peripheral and extrapersonal space in the real environment and virtual reality. We hypothesized that there would be similar brain activity at each of these environments depending on the focal distance of an object from the participant. Peripheral space is the visual space that is a reachable distance from a person. It has an overall neural pattern in the dorsal stream of the brain. Extrapersonal space is the visual space that does not directly surround a person and cannot be directly acted on. The overall neural pattern involved is in the ventral stream of the brain. In virtual reality, a person is able to interact with the virtual world presented just as they would with the real-world environment. They experience peripheral and extrapersonal space even though the device they wear is only inches away from their eyes. Data in this experiment was taken using electroencephalography (EEG). It was processed and analyzed using EEGLAB, a program of the computer software MATLAB. After data analysis, it was found that in the real environment and virtual reality in a person's peripersonal space, there was neural activity in the intraparietal cortex of the brain and along the dorsal pathway of the brain. When studying visual perception in a person's extrapersonal space, it was found that in the real environment and virtual reality, there was neural activity in the ventral occipital cortex and activity in the medial temporal cortex of the subject's brain. This correlates to what we anticipated to happen after studying previous research on visual perception in the real world. In the future, we hope to be able to take data on a greater variety of participants as well as add trials studying the effect of augmented reality. This will give us an even better idea of the way the brain reacts while seeing objects at different focal distances in a variety of environments.

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INTRODUCTION

Previous studies have shown that the visual system is able to process information differently depending on the focal distance from the eyes to an object. This is because the brain contains modular representation of space where there is a dissociation between peripersonal space and extrapersonal space in vision [1, 2]. Also known as a person's reachable space, peripersonal space is the near space that immediately surrounds a body. Extrapersonal space is space away from a person's body beyond what they are able to reach. When studying brain activity, it can be seen that different parts of the brain are activated depending on the distance away from an object a person is standing [3].

In this study, we will discuss the effect that Virtual Reality (VR) has on visual perception and brain activity at different focal depths. VR is a three-dimensional, computer generated environment that is presented to a viewer [4]. In VR, a person is able to interact with the virtual world just as they would interact with the real world. Objects appear to be in both peripersonal space and extrapersonal space just as they would in real life even though the distance of the object is only inches away from the eyes [4]. This concept has been used in multiple areas other than engineering such as within education, the military, healthcare, and business [4].

The purpose of this research project is to determine the similarities and differences of neural activity while a participant fixates on objects in their peripersonal and extrapersonal space in both the real environment and in virtual reality. Neural activity will be recorded using electroencephalography and analyzed using EEGLAB. We hypothesize that the different brain regions associated with peripersonal and extrapersonal space in the real environment will also be observed when a subject is focusing on an object at different visual depths in VR.

CHAPTER 1: BACKGROUND

1.1 Peripersonal and Extrapersonal Space

Evidence shows that the brain contains modular representation of space in the different cortical regions that process peripersonal and extrapersonal space. Peripersonal space is the space that is near and in reachable distance from a person. Extrapersonal space is the space that is far away from a person and cannot be acted on directly by the body [1–3]. See Figure 1 for a depiction of peripersonal and extrapersonal space.

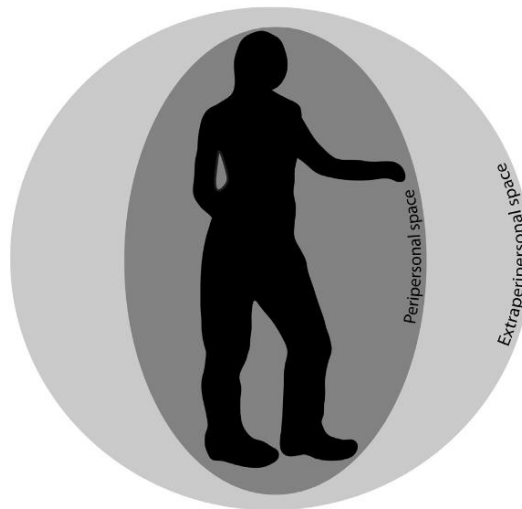


Figure 1: Peripersonal and Extrapersonal Space

This figure shows the peripersonal or reachable space around a person as well as the extrapersonal or unreachable space around a person. [2]

Research shows that with near space, the overall neural pattern is associated with the dorsal visual stream of the brain. With far space, the overall neural pattern is associated with the ventral visual stream [3, 5]. The dorsal stream carries visual information from the primary visual

cortex to the parietal lobe. The path is sometimes known as the “where” pathway because it is related to the movement and controlling of actions in spatial processing [6, 7]. It focuses on characteristics for action such as the location, movement, spatial transformations, and spatial relations of objects [8]. The ventral stream carries information from the primary visual cortex to the temporal lobe. This is most often called the “what” path because it focuses on the identification of objects [7, 9]. It focuses mainly on characteristics of perception such as the color, texture, pictorial detail, shape, and size of an object [8]. Figure 2 reveals a depiction of the dorsal and ventral streams in the brain.

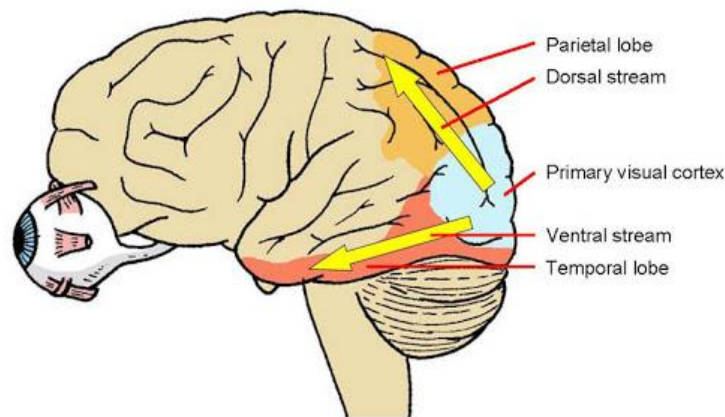


Figure 2: Dorsal and Ventral Streams of Visual Pathway

This dorsal pathway is known as the “where” pathway and controls spatial processing. The ventral pathway is known as the “what” pathway and controls the characteristics of perception. [10]

1.2 Virtual Reality

Virtual reality (VR) is a technology that causes the brain to be able to recognize the difference between peripersonal and extrapersonal space even though a VR device is only inches away from the eyes [4]. It is a three-dimensional computer-generated environment of which one is able to

easily explore, interact, and become a part of the virtual world being presented [4, 11]. In other words, VR gives people a “sense of presence” in this newfound virtual world [4]. VR can be experienced through headsets, omni-directional treadmill, or special virtual gloves, and is involved in a multitude of applications including the areas of architecture, medicine, sports, and arts [4]. In this study, an HTC Vive head-mounted display (HMD) (Figure 3) will be used to allow the subject to enter virtual reality. The neural activity, as the participant views objects in their peripersonal and extrapersonal space, will be studied using the electrodes of an EEG cap.



Figure 3: HTC Vive HMD

This is the VR device being used in the current experiment. [12]

1.3 Augmented Reality

Augmented reality (AR) was first introduced in the 1950s by cinematographer Morton Helig. He had a vision for the “Cinema of the Future” that allowed cinema to have the ability to have the viewer take in all their senses [13, 14]. AR is different than virtual reality in the fact that it adds a virtual sense to the real world that a person would normally see and interact with [15]. This current

idea of a virtual world being encompassed with the real world was established in 1997 by Ronald Azuma [13, 16, 17]. There have been many developments involving AR in the areas of medicine, the military, and entertainment. AR is able to enhance the capabilities of the human senses with augmentation of sight, smell, touch, and hearing. It has demonstrated to aid in those that are missing a sense such as providing audio cues to those that are completely blind or have severe visual impairments or aiding the deaf by providing visual cues [13].

We hope to use this newly developed custom-built optical see-through AR HMD (Figure 4) in future experimentation to study neural activity of subjects focusing on objects at different focal distances in AR. This will allow us to further our investigation on the effect that objects in peripersonal and extrapersonal space have on the brain's activity.



Figure 4: Custom-built optical see-through AR HMD

This device will be used in future experimentation with augmented reality (AR)

1.4 Previous Studies

There has been a variety of research showing the dissociation in peripersonal and extrapersonal space. In 2000, Weiss et.al, studied the neural activity relating to peripersonal and extrapersonal fields using PET scans to highlight the areas of interest. In this study, subjects were asked to point or bisect lines using a laser pointer in both near and far space. They found that vision in the peripersonal field showed activity in the dorsal visual cortex including the left dorsal occipital cortex, left intraparietal cortex, left ventral premotor cortex, and left thalamus [3]. When performing tasks in the extrapersonal field, there was neural activity in the ventral visual cortex including areas of the right medial temporal cortex and the bilateral ventral occipital cortex [3]. Figure 5 shows a visual of the neural activity in near and far fields.

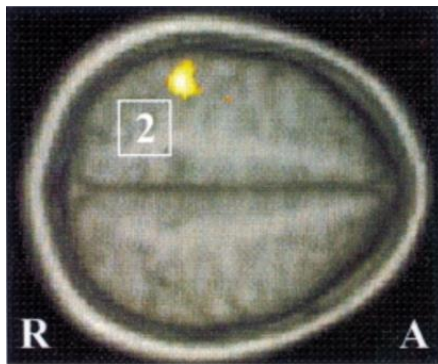


Figure 5.1: Near Field
Activation field of the left intraparietal cortex (2).

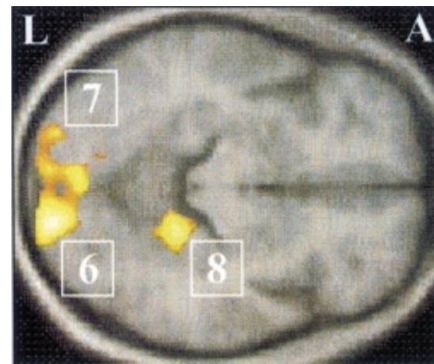


Figure 5.2: Far Field
Activation field of the medial temporal cortex (8) and the bilateral ventral occipital cortex (6 and 7)

Figure 5: PET scans showing near and far activation

[3]

In 2007, Gamberini et. al, conducted a study to test left spatial neglect involving line bisection [1]. Spatial neglect affects processing of contralesional spatial information after a unilateral damaging to the brain [1, 18]. During testing, a patient is shown a horizontal line segment with the midpoint in line with the patient's body, and the patient was asked to bisect the line segment. It was found that there can be a direct shift of midpoint, suggesting that there was a change from peripersonal space to extrapersonal space when the patient used a laser pointer. However, when a stick was used to extend the pointing ability, there was no change in midpoint. This suggested there was an extension of peripersonal space into extrapersonal space. The study was repeated but in virtual reality showing similar results [1]. This gave evidence in the ability to use virtual reality to further the explanation of a dissociation between peripersonal and extrapersonal space.

These studies were used to help develop this current study. We have used the information provided about neural activity in both near and far space in the real environment to help predict what will happen in virtual reality.

1.5 Dipoles

An electric dipole consists of pairs of equal and opposite electric charges that are separated by a certain distance and is a vector running from positive to negative [19]. A dipole moment is considered the measure of strength within an electric dipole. It is known to be the product of the of a charge and the distance between the charges [19]. This can be shown in Figure 6.

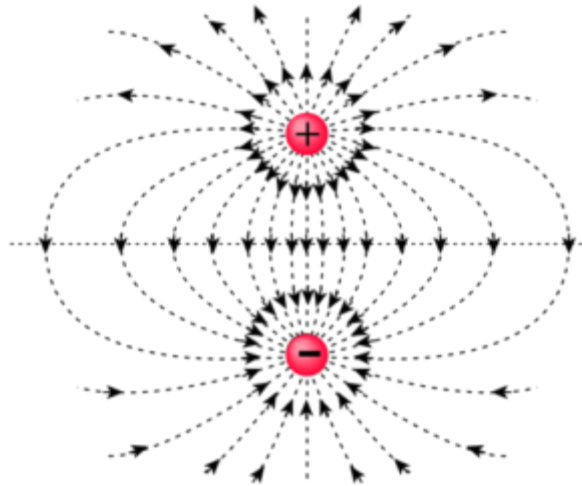


Figure 6: Electric Dipole

This figure represents the charges that make up an electric dipole. [19]

In this study, dipoles are found using DIPFIT, a method of EEGLAB, to show overall neural activity distribution across the scalp. EEGLAB is a program that analyzes EEG data within the computer programming software MATLAB. A number of equivalent dipoles are represented by an overall scalp distribution using DIPFIT as seen in Figure 7. While it is difficult to obtain the exact locations where the dipoles or voltage drops occur, the DIPFIT program provides the “best fit” solutions that are displayed as dipole maps and represent the overall scalp distributions [20].

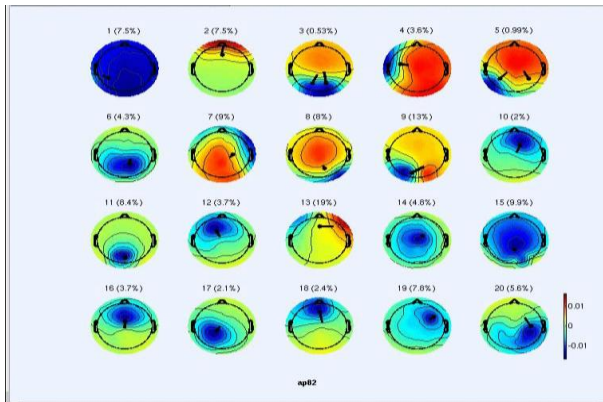


Figure 7: Scalp Maps

This figure represents what scalp maps may look like from EEGLAB. [20]

CHAPTER 2: STUDY DESIGN/PROCEDURE

2.1 Objective

To determine the similarities and differences in regions of brain activity when fixating on objects in near and far space in the real world and in virtual reality.

2.2 Design

The design involves a 3x2 (environment x distance) factorial. Each subject is involved in one trial of each distance (near, 75cm and far, 2m) in each environment (real and virtual). The fixation point is a crosshair subtending 5 degrees in the visual field displayed in the center of a computer monitor resting on a table. The table is physically moved to the distance condition each time. The real environment consists of this table and a whiteboard on the wall in the background. The environment is kept mostly visually sparse, but a computer and a few monitors are visible in the far periphery. The virtual environment is a close replica of the real environment built with Unity3D. Geometrically, it is identical except for the computer and monitors in the periphery. All objects are colored or textured to match their real-world counterparts, and the table/monitor is motion-tracked with a Vive tracker so that the position and orientation of the virtual table always matches the real table. The crosshair is rendered so that it appears in the center of the real monitor and at the same depth in space as the surface of the monitor. In the real environment, the crosshair is controlled via a laptop placed behind the monitor. The virtual environment is seen through an HTC Vive HMD.

2.3 Data Collection

Subjects first fill out a consent form, simulator sickness questionnaire, and a demographics questionnaire. The subject is then asked to sit in a chair, and the experimenter places a 33 electrode EEG cap on their head. EEG data was taken using Neuroscan data acquisition software (2007). The impedance was reduced to below $5k\Omega$. The sampling rate was set to 250 and the EEG data was re-referenced to electrode A2. The procedure is explained to them. Eye height (measured from the floor while in a seated position) and arm length (measured from the subject's back to the tip of the outstretched index finger) are measured. The table is adjusted so that the center of the monitor is approximately at the subject's eye level. The arm length is used to verify that the near condition is within reach. Subjects then close their eyes, and the table is moved to the first distance condition. After a countdown is given by the experimenter, the subject opens their eyes and fixates on the center of the crosshair for 1 minute while thinking about pointing to the center. The experimenter tells the subject when time is up, and the subject closes their eyes again. The table is moved to the second distance, and the procedure repeats. After the second distance, the experimenter places a Vive HMD on the subject, and the procedure repeats in the virtual environment.

2.4 Data Analysis

The results of the data were analyzed in EEGLAB, a component of the computer software program MATLAB that allows for the analysis of EEG data [21], [22]. Multiple steps were required to prepare the data for dipole analysis. A basic linear finite impulse response (FIR) was used to aid in the removal of preliminary artifacts or unwanted noise. After this, excess artifacts that were not removed by the filtering were then removed using the channel scroll

option. This allows for the viewing of the EEG data at each second of the trial. This data was then processed using independent component analysis (ICA) which was used to help remove various signal artifacts. ICA involves a linear change of basis from single channel records to a collection of simultaneously recorded outputs. It separates components that are repeated throughout the original data set and lines them up in order of least to most effective to the overall data set. The data can then be analyzed to see if it is brain activity, muscle activity, or other extraneous noise being perceived. Figure 8 shows an example of a list of different components processed from ICA.

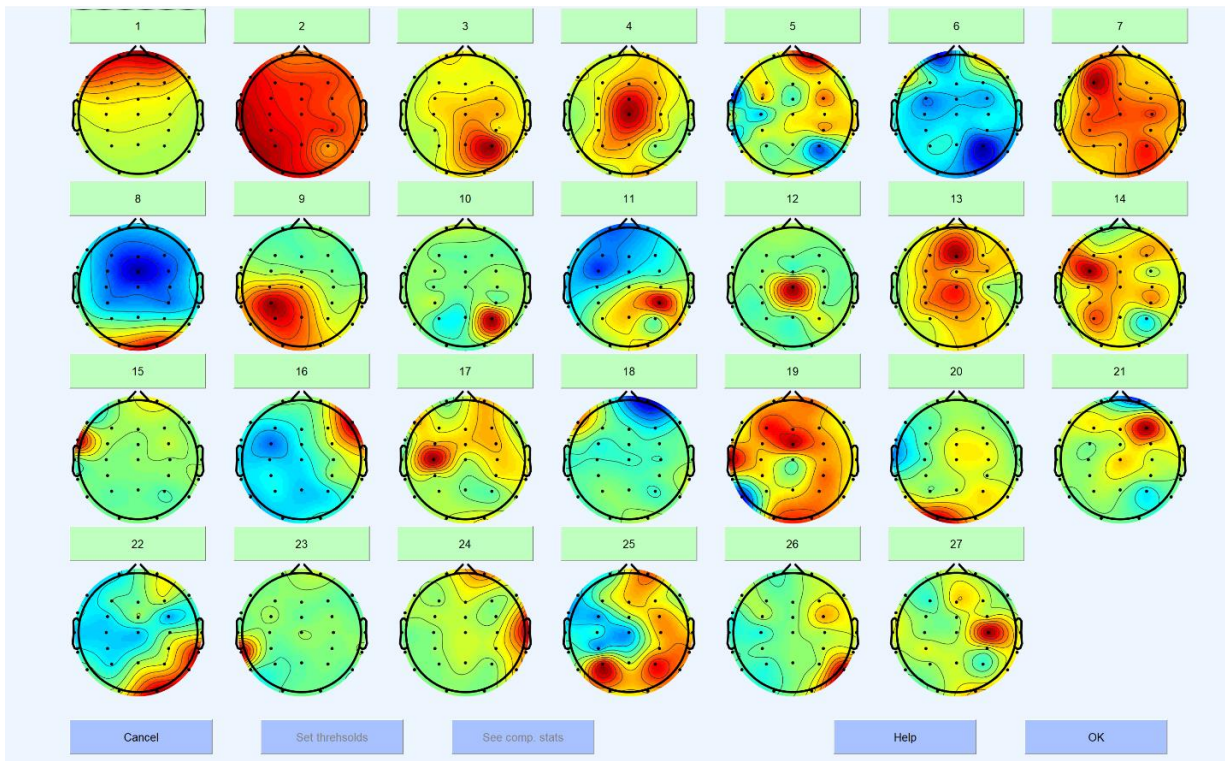


Figure 8:Component Map

Source: [20]

This figure shows scalp maps of each component from ICA

A blink artifact is a common artifact removed. Figure 9 shows a better look at component 1 which we know to be a blink artifact because of the increased activity in the frontal lobe of the scalp map. We reject this artifact in order to remove it and create a cleaner set of EEG data.

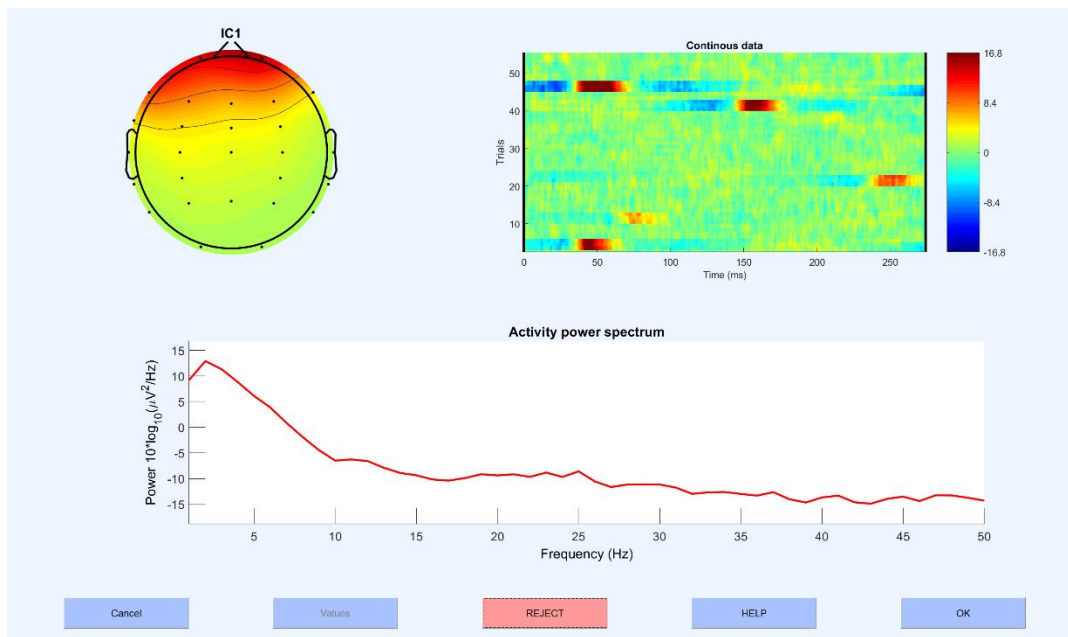


Figure 9: Blink Artifact

Source: [20]

This is a blink artifact from the list of scalp maps after ICA. This is shown by an increased amount of neural activity in the frontal lobe.

Before the component was removed completely, there was the ability for a comparison of what the data were to look like after removal. Doing this confirmed that the correct component was being removed from the data set. Figure 10 shows a portion of data after the component was removed. The difference in data is represented by different line colors. Black lines represent raw EEG data. Red lines represent EEG data after components have been removed.

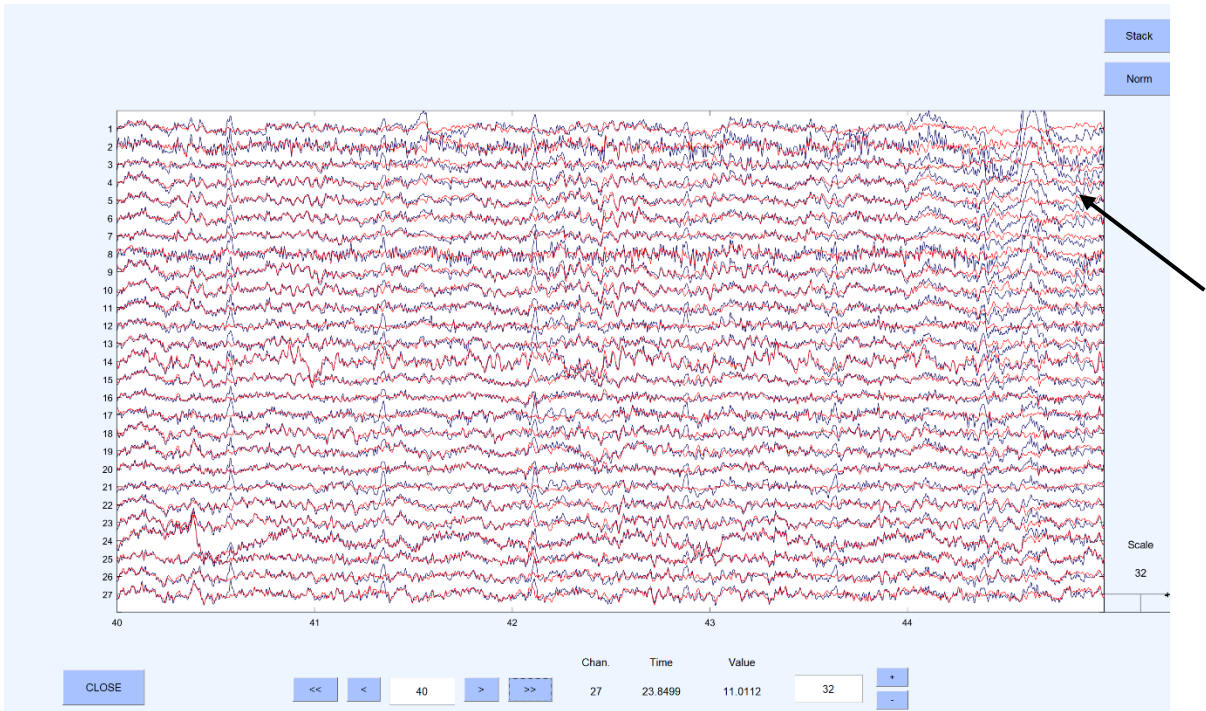


Figure 10: EEG Data After Component Removal

Source: [20]

The black lines show the data before the components were removed, and the red lines are from after the components were removed. The peaks denoted by the arrow represent what the data looks like after a blink artifact is removed.

The arrow in Figure 10 is pointing to a blink artifact in the EEG data. We know that this is a blink artifact because the intensity decreases as we move down the channels. The early numerical channels are located at the front of the EEG cap in the frontal lobe. Reactivity to the blink declines as it moves to the back of the brain.

Once the data were cleaned and filtered, the dipoles were located using DIPFIT. DIPFIT is a plugin in EEGLAB that localizes dipole moments from independent component maps [20]. These dipole moments can be shown by plotting on a 3-D moveable brain dipole map. In order to properly fit dipole models using DIPFIT, an independent component analysis (ICA) decomposition must be performed. To do this, first a dataset must be built or loaded, then

channel location files must be imported, so the ICA decomposition can be completed. To fit the dipole using DIPFIT, we located the head model and settings. We specifically used the boundary element (BEM) which is composed of three 3-D surfaces including the skin, skull, and cortex. The dipoles were then plotted using autofit. Figure 11 shows what a plotted 3-D moveable brain dipole map looks like [20].

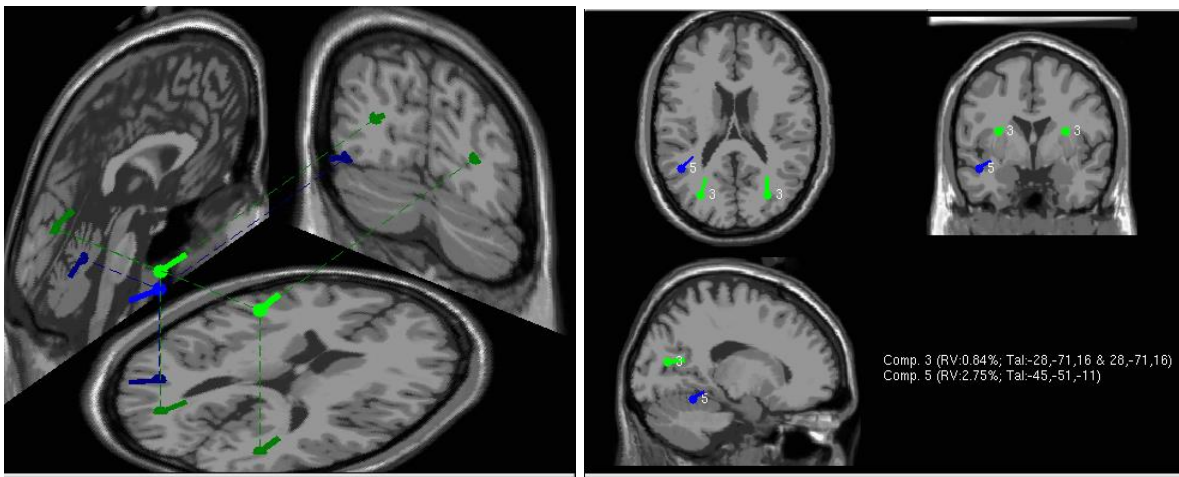


Figure 11:3-D Moveable Brain Dipole Map

Source: [20]

This figure shows dipoles presented on a 3-D moveable map

CHAPTER 3: RESULTS

This project involves the testing of a single subject at near and far distances in the real environment and virtual reality. The data were processed through EEGLAB, and the dipole moments were analyzed to find where there was neural activity during each condition using DIPFIT – a component of EEGLAB.

3.1 Real Environment in Subject's Peripersonal Space

Figure 12 shows dipoles moments when the subject was looking at in object in their peripersonal space in the real environment. It is shown that there was neural activity in the left and right intraparietal cortex. This is represented by the red circles in Figure 12. It can also be seen that there is neural activity in the dorsal pathway of the brain. This is represented by the blue circles that can be seen very well in the photo farthest to the right in Figure 12.

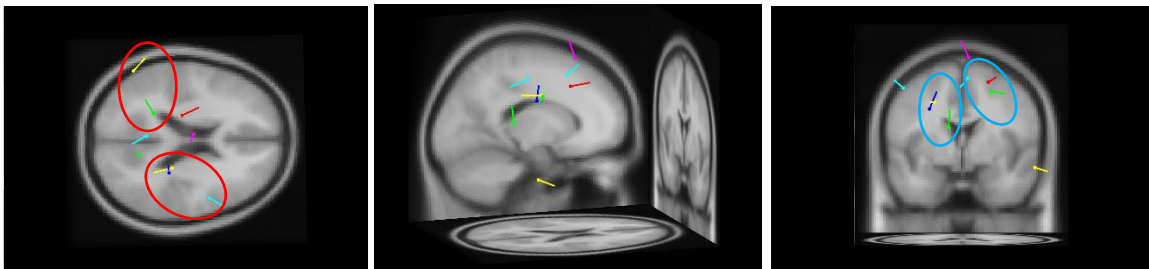


Figure 12: Dipole Maps of Real Environment in Peripersonal Space

The dipoles in the photos represent areas of neural activity when the subject was looking at an object in their peripersonal space in a real environment.

3.2 Virtual Reality in Peripersonal Space

Figure 13 shows dipole moments when a subject was looking at an object in virtual reality in their peripersonal space. There is activity in the subjects left intraparietal cortex shown by the red circles in Figure 13. There are also dipole moments showing activity in multiple places along the dorsal pathway of the brain as represented by the blue circles Figure 13.

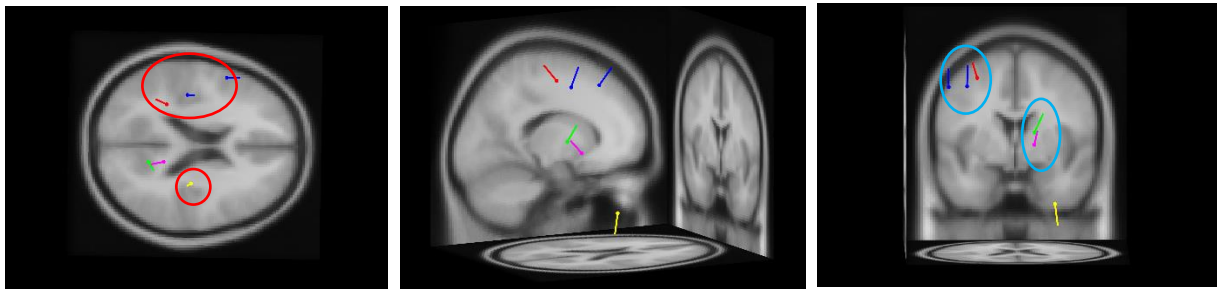


Figure 13: Dipole Maps in Real Environment in Extrapersonal Space

The dipoles in the photos represent areas of neural activity when the subject was looking at an object in their extrapersonal space in the real environment.

3.3 Real Environment in Extrapersonal Space

Analysis of Figure 14 reveals dipole moments when a subject looked at an object at a far distance in the real environment. There was activity in the ventral occipital cortex denoted by the yellow circles on Figure 14. It is also shown that there was also activity in the medial temporal cortex of the brain which is denoted by the blue circles on Figure 14.

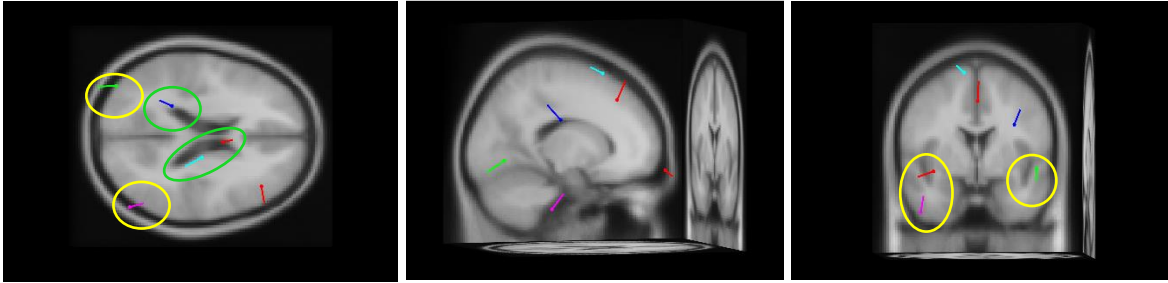


Figure 14: Dipole Maps in Virtual Reality in Peripersonal Space

The dipoles in the photos represent areas of neural activity when the subject was looking at an object in their peripersonal space in virtual reality.

3.4 Virtual Reality in Extrapersonal Space

Figure 15 shows dipole moments from the subject after they focused at an object in virtual reality in their extrapersonal space. The figure reveals that there was neural activity in the ventral occipital cortex of the brain that is shown by the yellow circles in Figure 15. There was also activity in the medial temporal cortex as denoted by the green circle in Figure 15.

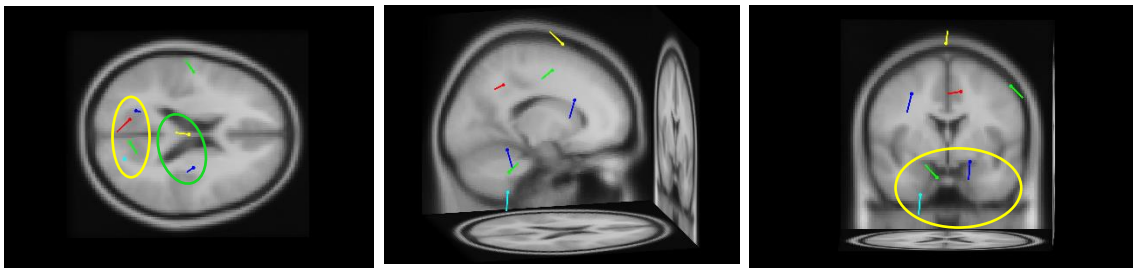


Figure 15: Dipole Maps in Virtual Reality in Extrapersonal Space

The dipoles in the photos represent areas of neural activity when the subject was looking at an object in their extrapersonal space in virtual reality

CHAPTER 4: DISSCUSSION

4.1 Review of Results

The research in this study involved the comparison of the similarities and differences in neural activity of placing an object in a person's peripersonal or extrapersonal space. The brain activity was analyzed in real environment and virtual reality. The data was collected using EEGLAB and analyzed with DIPFIT which allowed for analysis of dipole moments within the brain.

In the real environment, the data revealed that while a subject fixated on an object in their peripersonal space, there was some neural activity in the intraparietal cortex and the dorsal pathway of the brain. This is shown in Figure 12 and can be related to what we expected to find in regard to our research of previous studies. While the subject fixated on an object in their extrapersonal space, it was found that there was neural activity in the ventral occipital cortex as well as areas of the medial temporal cortex of the subject's brain. The activity can be seen in Figure 13. This activity again is very similar to what we expected to be presented after our research of previous studies. When looking at both figures 12 and 13, we can find dipole activity in alternate areas of the brain. This can be due to the fact that neural activity from other factors of the environment was occurring. This could also be due to noise within the data that was not able to be removed in the ICA.

In virtual reality, even though the device was only inches away from the subject's eyes, we were able to show that when the subject fixated on an object in their perceived peripersonal space, we found that there was neural activity in the left intraparietal cortex with other activity along the dorsal pathway of the brain. These activities can be seen in Figure 14. When the subject fixated on an object in their perceived extrapersonal space, we found neural activity in

ventral occipital cortex as well as in the medial temporal cortex. The activity can be shown in Figure 15. All of these neural responses were related to what we anticipated based on our research of past studies. However, just as mentioned in the discussion about neural activity in the real environment, we found activity in other parts of the brain. These could be from exterior noise in the EEG data or other brain activity.

With the data presented, we concluded that the different regions of the brain that were highlighted when fixating on an object in peripersonal and extrapersonal space in a real environment was very similar to that in virtual reality. This proves that our hypothesis was valid in the fact that the brain is able to differentiate between different types of space in both the real world and when in virtual reality.

4.2 Future Experimentation

Due to the COVID-19 pandemic, we were unable to continue data collection resulting in us only collecting data from one participant. Our hope is to be able to continue our study with more participants as well as add an additional trial with augmented reality. This will help us to better find the impact that fixating on objects in a person's peripersonal and extrapersonal space in a variety of environments has on neural activity.

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