Cognition in Digital Environments

A study on the effects of Virtual Reality on the human brain

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***Abstract* – This paper explores the differences in the state of the human brain when immersed in Virtual Reality(VR). VR has received a lot of academic, corporate and public attention in the past two years with the release of the first wave of mainstream, publicly available and affordable devices. Very little research has been done, however, in the effects of the use of such devices on the human brain. This paper proves there are differences in the brain activity when using VR as opposed to more traditional media and provides an estimate on their extent. Towards that end the brain activity of a group of 18 volunteers, 18-25 years old, male and female, was measured using a highly accurate, 14-channel, research-grade Electroencephalographer (EEG). The measurements were first performed while the subjects were idle, then as they were using a classical, first person game via a monitor and finally when they wore a VR headset (Razer OSVR Hacker Dev kit) while experiencing a custom, realistic 3D environment. These measurements were then translated into six mental states, Engagement, Excitement, Interest, Relaxation, Stress and Focus while taking into account the individuality of the human brain. The differences in these mental states between the three activities (idle, monitor, VR) were calculated and presented using summary statistics. Outliers were taken into account and other methods were implemented to ensure data quality. From the six mental states, the one most affected by the use of VR was Excitement with a mean difference of 26.4% between the VR and the traditionally experienced environment, followed by Focus with an increase of 14.5% and Interest increasing by 12.1%. Stress levels were also elevated by 13.3% while using VR. All in all, experiencing a digital environment in VR is more interesting, much more exciting and increases focus, at the cost of a more stressful overall experience.**

Keywords – virtual reality; VR; cognition; EEG; brainwaves;

I. Introduction

Virtual reality, an emerging technology, is defined as the artificial environment which is created by software and presented in such way that the user suspends belief and accepts it as a real environment. On a computer, VR is primarily experienced through two of the five human senses, sight and sound.

The recent breakthroughs in this field, including the creation of publicly available and affordable VR hardware and the technical evolution of personal computers have led to a huge increase in public and corporate interest. That being the case, not much research has been done in the area of human cognition and brain activity under the effects of Virtual Reality.

A paper[1] exploring the effects of VR in the hippocampus area of the rat brain had researchers surprised to discover huge differences between activity in that particular area of the brain on rats exploring a real and a virtual environment that were designed to look the same. No attempt has been made, however, to discover and analyze the differences in the human brain when experiencing a VR environment as opposed to a digital environment through a conventional screen, even though it's an area of great interest to users and developers alike.

This paper attempts to prove such differences exist, analyze them, explain the results by linking brain activity to human emotions and prove that the effects of VR on the human brain warrant further, more thorough investigation. Towards that end, a realistic digital environment was created and properly rendered through a VR headset. Every tester wore the device along with a portable electroegephalographer and experienced the digital world through Virtual Reality. Then, the individual would experience another digital environment, this time rendered through a classic PC screen. A third measurement would be taken with the individual being inactive for referential purposes. The data were, then, processed and compared so that assumptions on their meaning could be made.

II. Hardware

A. Virtual Reality (VR)

VR has existed (in some form) since 1838, when Charles Wheatstone discovered that the brain processes a different, two-dimensional image from each eye to form three dimensional objects. Viewing two side by side stereoscopic images or photos through a stereoscope gave the user a sense of depth and immersion. The later development of the popular View-Master stereoscope (patented 1939), was used for "virtual tourism". That very same principle is also used in modern devices such as Google Cardboard and low-budget VR head mounted displays.

The 21 century has already seen rapid advances in the field, with 2016 being a key year having companies like Facebook and Valve investing billions on it. While almost every aspect of VR is being advanced. the bulk of attention revolves around the development of affordable, personal, head-mounted displays and various other accessories, usually in the form of hand-held, gesture and motion tracking hardware that enable deeper immersion and further ways of interaction with the digital environment. For the present experiment, the OSVR Hacker Dev kit headset was used.

The OSVR is a high-end device, manufactured by Razer, it has an open-source design and is primarily aimed at developers. The reasons for choosing this device over the competitors were availability (was available to developers more than half a year earlier than the other products), the noticeably lower price and the open-source design. On the other hand, using this high-end headset instead of simpler solutions, like the Google Cardboard, ensured the quality of the VR experience and the accuracy of the data collected.

B. *The Electroegephalographer*

The brain is a very complex system. The frontal cortex, the region where most of the conscious thoughts and decisions are made, conducts much less than a tenth of the total activity in the brain. Planning, modeling of our surroundings, interpretation of sensory inputs up to and including our perception of reality, memory processing and storage and the basic drivers of our moods and emotions occur in many functional regions distributed around the brain, including the visual cortex at the rear, temporal cortex at the sides, parietal cortex behind the crown of the head and the limbic system deep inside the brain.

The limbic system controls the basic moods and emotions, the fight/flight response and deeper long term memory encoding as well as control of basic bodily functions such as breathing and heartbeat. Most of these deeper functions interact intimately with different parts of the cortex (the outer layer which is accessible to EEG measurements) however the interaction is quite complex and distributed. In order to map the true activity of the brain it is very important to measure signals from many different cortical structures located all around the brain surface. It is not possible to map these signals purely from the frontal and temporal regions. Determination of the user's complete mental state is very poorly approximated unless signals from the rear of the brain are also considered. With proper coverage and electrode configuration, it is possible to reconstruct a source model of all important brain regions and to see their interplay.

Figure 1 showcases the accuracy of the Epoc+ EEG system used in this experiment. Even when compared to Research-type equipment (worth around $60,000), the data retrieved are similar. EMOTIV, the company behind Epoc, currently provides drivers that measure 6 different emotional and sub-conscious dimensions in real time – Excitement (Arousal), Interest (Valence), Stress (Frustration), Engagement/Boredom, Attention (Focus) and Meditation (Relaxation). These emotional states were developed based on rigorous experimental studies involving at least 20-30 volunteers for each state, where subjects were taken through experiences to elicit different levels of the desired state. They were wired up with many additional biometric measures (heart rate, respiration, blood pressure, blood volume flow, skin impedance and eye tracking), observed and recorded by a trained psychologist and also self-reported. EMOTIV Performance Metrics have been validated in many independent peer-reviewed studies[2][3]. The present experiment uses these categories (emotional states) to determine the effect of VR on the average 18 to 25-year-old human.

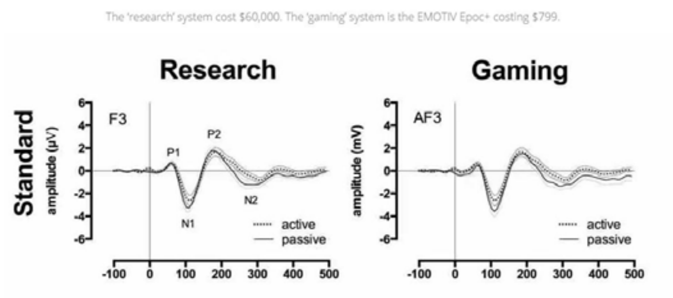

Figure 1

III. THE DIGITAL ENVIRONMENT

When comparing the reaction of the brain to two differently presented digital environments, the parameters of the environments themselves have great effect on the accuracy of the data received. In order to make data as comparable as possible the two environments in question should be similar, yet not the same. This would ensure that the subjects will not be getting familiar with the setting, endangering the validity of the data in the second measurement. The easiest method for achieving this is providing two similar and realistic environments, experienced in first person, and ensuring that all testers be unfamiliar with both.

Due to the VR market being at its infancy at the time of the experiment, there were no suitable environments made publicly available. That being the case, a new one had to be made for our purposes. This environment was created in Unity, utilizing and repurposing, mostly free, assets and made to comply with all the suggestions and limitations provided by Oculus for the creation of seamless, enjoyable and overall proper VR experiences. For the traditionally presented environment, there was no need for custom creations. A first-person game under a free license was chosen, with realistic graphics, directly comparable to the above. For discretion purposes, the exact name of the software will not be disclosed, but it can be described as a typical first person shooter with the weapons not being utilized in the testing phase, which would, in fact, make it a first-person, exploration game.

IV. THE TESTERS

The measurements were taken from 18 volunteers, university students, 18 to 25 years old, male and female, most of whom were interested in trying VR for themselves. Before the test, they were instructed to fill an incognito survey on their age, gender, experience with digital environments and VR.

Each survey was linked to the data via a serial ID number. From the data collected, the average tester can be considered being 22 years old, having 21.8 hours per week in digital worlds (mostly gaming) and no experience in VR.

The testers were then separated into two groups. This was done due to a very practical problem. The head-mounted VR display and the EEG were physically semi-compatible and could be properly worn together, but there was some degree of discomfort in doing so. *Group 1* was tested while having both devices properly placed on them while *Group 2* was tested with only the EEG properly mounted on their heads and the VR headset being held against their faces with their right hand.

The above proved more comfortable, yet slightly limited the overall movement both within and out of the digital environment. The end results were first calculated without any group segmentation and then for each group separately. Gender was also taken into account in the calculations, since some very distinct and impressive differences were discovered between male and female cognitive activity.

V. Testing Phase

The human brain, which is at the very heart of this experiment, is extremely sensitive. The biggest problem faced was to ensure that changes observed between the readings on a tester were caused by the experiment and not some other, unforeseen factor as abstract and elusive as a thought or a mood swing. While absolute data quality is not feasible, steps were taken to ensure that the environment where the test took place had uniform effects across all tests.

- The temperature was controlled and maintained at 23 degrees Celsius, which is the recommended room temperature for humans during the summer[4].
- Testers were encouraged to abstain from distractive actions during the time of the testing.
- Tests were re-performed when presumably important, unpredicted and unique to a testing events took place.
- Large breaks between the testing phases ensured testers could properly focus on the tasks given.
- The room itself remained unchanged during the duration of the experiment.
- Participants were treated in similar ways and communication, especially during the testing itself, was worded carefully and uniformly across all testers.

Readings from each tester were obtained in three stages.

A. Stage One: Preparation

The first stage of the experiment involved the tester getting familiar with the procedure and the environment. They were asked to fill in the personal survey and they were given a summary of the procedure. During this stage, the EEG was installed on the individual and calibrated using Xavier, the platform offered by Emotiv to control the device, interpret the data received and ensure their quality.

For the calibration, a new profile was made for each user, referenced by a serial ID (the same used on the survey). The normalization performed in the data of each individual based on previous values means that only one individual should use each profile, as it will be tailored to them and their personal readings. After explaining the procedure, a calibration was performed that was required for the use of the *Recording* function of Xavier. This function receives the raw data from the hardware, interprets them and maps them into 6 different emotional states. To achieve optimal mapping, it first needs personal user calibration involving readings with the eyes open and closed.

After the calibrations are complete, a one-minute-long data capture was performed using the *Recording* function of Xavier while the tester remained generally inactive. This served as a basic measurement for quality control and as a hardware check.

B. Stage Two: The Classic Environment

The second stage involved a one-minute recording of the tester experiencing a 3D, first person game through a 23inch, high quality screen. They were instructed to explore the digital space as they saw fit. This environment was a faithful copy of multiplayer, first-person shooters such as Counter Strike with a relatively small arena to explore, the weapons left mostly unused since their use was pointless (their use enabled and left to the discretion of the player) and the multiplayer part removed. This, in effect, created a lively, 3D environment that the tester could explore. After the measurements were finished, the data collected were properly tagged and saved.

C. Stage Three: The VR Experience

The third stage begun by the tester wearing the OSVR headset. Group one testers would wear it properly and as comfortable as possible and then were offered the game controller, which they operated using a classic PS3 controller (their vision was obstructed by the headset) while group two testers had the headset properly placed on their faces, without the harnesses, and were asked to hold it firmly there with one hand while operating the controller joystick with the other. Then, all groups were asked to calibrate the headset, move it and re-focus the lenses to achieve perfect stereoscopic vision. Failure to do so properly produced strong feelings of nausea, so this step was of great importance to the experiment. Specifically, the testers were asked to watch the center of the (build-in) screen right in front of their eyes and move the device and adjust the lenses in front of each eye until it became completely focused and clear. Then they were asked to explore the world as they saw fit, just like they did in phase two, for one minute while Xavier was recording their data. Then it was properly tagged and saved.

VI. Results

The data obtained were stored by Xavier in the form of 6 self-explanatory emotional states: Engagement, Excitement, Interest, Relaxation, Stress and Focus. These states were represented by a percentage. An individual with an average Stress reading of 90% would probably be feeling stressed at the time the readings took place. All in all, the data obtained were 6 percentages representing the above mental states, for each phase. Then, the differences between same emotional states in different phases were calculated for every tester.

The easiest way to understand the differences between groups of data and to mathematically present them is Summary Statistics. For the present analysis, the mean (the sum of a collection of numbers divided by the number of values in the collection), median (the value separating the higher part of a data sample from the lower part) and mode (the value that appears most often in a set of data) will be calculated for every emotion. The first two for the actual result representation and the last one for quality control. First, we calculate the differences between the values obtained in Phase One and Phase Three, then Phase Two and Phase Three. This is done to all 18 IDs. Then, the mean and the median will be calculated between all the corresponding values(differences) of all the testers. We do this for every emotional state. Then we calculate the mode and check if it contains the 0 value, which would mean that there were many duplicate readings. An example would be Stress being 100 for all 3 readings of a volunteer. The logical assumption is that the reading was false, an outlier and that we should remove it from the data pool. Below, the results are presented using graphs and summary statistics. In paragraphs A to F the effects of VR in each emotional state is being presented (Calm=Phase1, FPS=Phase2, VR=Phase3). Negative values demonstrate a decrease in the emotional response.

A. Engagement

Engagement is defined as emotional involvement or commitment. Results indicate small overall changes in engagement between the different phases.

Engagement results (*Table 1*):

Table 1

-	-	ALL	No Outliers	Group 1	Group 2
Calm – VR	mean	-0.111	0.562	-3.250	2.222
FPS – VR	mean	-1.777	-1.500	-2.000	-1.000
Calm – VR	median	1.500	1.500	-3.000	3.000
FPS – VR	median	-1.000	-2.000	-4.000	0.000

Female deviation from the average mean (negative values are lower than average) (*Table 2*):

Table 2

-	Group 1	Group 2
Calm – VR	-11.25	5.778
FPS – VR	-5.500	6.500

There are minor differences in Engagement from phase to phase, with the mean values getting closer to the medians after we remove the outliers, meaning our results get more robust. The above results are interpreted as Engagement slightly decreasing when feeling slight discomfort (Group 1), but remaining the same overall when using VR as opposed to more traditional means. It's noteworthy, though, that female testers demonstrated more than twice the engagement increase of the average, which dropped 2-3 times lower than the average when in slight discomfort.

B. Excitement

Excitement is a feeling of eager enthusiasm and interest. This is the emotional state with the most fascinating, definite difference in VR. Female deviation from the average is large for this emotional state too.

Excitement results (*Table 3*):

Table 3

-	-	ALL	No Outliers	Group 1	Group 2
Calm – VR	mean	12.000	12.000	9.666	14.333
FPS – VR	mean	20.555	20.555	14.666	26.444
Calm – VR	median	13.000	13.000	17.000	9.000
FPS – VR	median	22.000	22.000	17.000	26.000

Female deviation from the average mean (*Table 4*):

Table 4

-	Group 1	Group 2
Calm – VR	-7.833	5.834
FPS – VR	-15.444	9.834

The testers exhibited very big differences in this emotional state when experiencing a world through VR as opposed to more traditional means. A similar (26.5 to 26%) mean and median demonstrate that no big outliers exist in the data of Group 2, so that result is the most robust. An increase of 5-12% can be noticed between the group feeling slight discomfort (Group 1) and the other, comfortable group (Group 2). Furthermore, with the minimum increase of Group 2 at 5% and maximum at an incredible 58%, this was the emotional state influenced most by VR. Female deviation was also high regarding Excitement, with an increase of 5.8-9.8% when comfortable and decrease of 7.8 to 15.4% when in slight discomfort.

C. Interest

Interest is a quality that attracts your attention and makes you want to learn more about something or to be involved in something. This was the most robust set of data, with no outliers detected and mean values being, generally, close to the median.

Interest results (*Table 5*):

Table 5

-	-	ALL	No Outliers	Group 1	Group 2
Calm – VR	mean	2.055	2.055	2.111	3.000
FPS – VR	mean	9.853	9.853	6.555	12.111
Calm – VR	median	0.500	0.500	1.000	0.000
FPS – VR	median	10.500	10.500	7.000	12.000

Female deviation from the average mean (*Table 6*):

Table 6

-	Group 1	Group 2
Calm – VR	-2.611	3.000
FPS – VR	-0.515	2.389

The same motif appears in this emotional state as well. Group 2 exhibits a substantial increase when using VR, especially when compared to playing a game through classic means., while group 2 demonstrates a much smaller increase. Gender does not affect Interest as much, with minor (2-3%) differences exhibited.

D. Relaxation

Relaxation is something that stops someone from being nervous or worried. VR increased relaxation for all genders in a minor way. This state had the most outliers, possibly due to the relevant sensors being easier to move out of place, especially when worn under a VR headset.

Relaxation results (Table 7):

Table 7

-	-	ALL	No Outliers	Group 1	Group 2
Calm – VR	mean	1.277	1.533	4.500	0.000
FPS – VR	mean	2.529	3.000	2.500	3.000
Calm – VR	median	0.000	1.000	1.000	0.000
FPS – VR	median	3.000	3.000	3.000	3.000

Female deviation from the average mean (*Table 8*):

Table 8

-	Group 1	Group 2
Calm – VR	-3.500	-2.000
FPS – VR	0.500	5.500

Small differences for this emotional state in combination with many outliers and a relatively large difference between mean and median render these results uninteresting.

E. Stress

Stress is a state of mental tension and worry. There are big differences here from group to group and among readings. This was probably caused by either the lenses of the VR not being properly adjusted to each individual (something they could only do and notice themselves) which caused nausea or a conductivity-sensor problem in the EEG that sometimes caused stress to spike at 100%, an impossibility.

Stress results (*Table 9*):

Table 9

-	-	ALL	No Outliers	Group 1	Group 2
Calm – VR	mean	-6.166	-7.583	-9.571	-4.800
FPS – VR	mean	3.441	6.230	0.742	13.333
Calm – VR	median	-2.000	-6.500	-13.000	-4.000
FPS – VR	median	6.000	8.000	1.000	12.500

Female deviation from the average mean (*Table 10*):

Table 10

-	Group 1	Group 2
Calm – VR	-14.071	-2.300
FPS – VR	0.358	-0.833

F. Focus

Focus is defined as a center of activity, attraction, or attention. It had the second biggest increases of all the emotional states and was largely indifferent to genders.

Focus results (*Table 11*):

Table 11

-	-	ALL	No Outliers	Group 1	Group 2
Calm – VR	mean	5.055	5.055	2.888	7.666
FPS – VR	mean	12.333	12.333	10.111	14.555
Calm – VR	median	6.500	6.500	8.000	5.000
FPS – VR	median	13.000	13.000	7.000	14.000

Female deviation from the average mean (*Table 12*):

Table 12

-	Group 1	Group 2
Calm – VR	-1.888	0.334
FPS – VR	-5.111	-1.555

The above can be interpreted as a tendency of humans to focus more on a digital environment when using VR. The fact that eyesight is devoted to the digital world when experienced through VR may be the explanation to this. Gender plays a minor, insignificant role on Focus.

VII. Conclusion

Figure 2 does an excellent job of showcasing and summarizing the results. Note that Stress for members of Group1 is missing its values, presumably due to the pressure applied by the OSVR headset on the EEG.

The mean difference values were chosen for this graph since they are considered to depict the differences with higher accuracy.

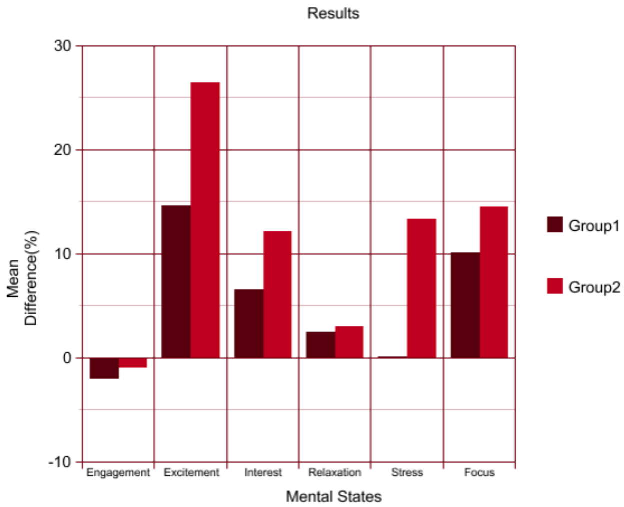

Figure 2

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Table 11