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Analysis of the Brain Activity of Virtual Reality users through Electroencephalogram (EEG)

Análisis de la actividad cerebral de usuarios de realidad virtual a través de electroencefalograma (EEG)

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Abstract:
The electroencephalogram (EEG) is a very useful tool to analyze the reactions of the brain through the consumption of content linked to the use of virtual reality (VR) technology. Our proposal consists of a neuroscience-based methodology where we explore the effects of VR on users' brain activity. This methodology can provide a valuable method to better understand the functioning of the brain and its relationship to the perception of stimuli elicited by the use of VR. At the same time, we believe that neuroscience can inspire and enrich the use of VR in the creation of new artistic forms, entertainment experiences and, in general, as an innovative communication medium exploring new frontiers unknown until now by users and audiences. This research can also have applications in fields such as psychology, neuroscience, psychiatry, and media and entertainment studies, as well as being a valuable tool for content creators, who thus obtain information to decipher consumer tastes. In this way, each specialist in his or her discipline will be able to obtain data that they can apply in a practical way to intervene in their respective fields of operation.

Keywords:
Electroencephalogram; Virtual reality; Immersion; Presence; Emotions; Neuroscience; Neurocinematics

Resumen:
El electroencefalograma (EEG) es una herramienta muy útil para analizar las reacciones del cerebro a través del consumo de un contenido vinculado al uso de la tecnología de realidad virtual (RV). Nuestra propuesta consiste en una metodología basada en la neurociencia donde exploramos los efectos de la RV en la actividad cerebral de los usuarios. Esta metodología puede proporcionar un valioso método para comprender mejor el funcionamiento del cerebro y su relación con la percepción de estímulos provocados por el uso de RV. Al mismo tiempo, consideramos que la neurociencia puede inspirar y enriquecer el uso de la RV en la creación de nuevas formas artísticas, experiencias de entretenimiento y, en general, como medio de comunicación innovador explorando nuevas fronteras desconocidas hasta ahora por usuarios y audiencias. Estas investigaciones pueden tener también aplicación en campos como la psicología, la neurociencia, la psiquiatría, y los estudios de medios de comunicación y entretenimiento, además de suponer una valiosa herramienta para los creadores de contenidos, que de esta forma, obtienen información para descifrar los gustos del consumidor. De esta manera cada especialista en su disciplina será capaz de obtener datos que pueden aplicar de manera práctica para intervenir en sus respectivos campos de operación.

Palabras clave:
Electroencefalograma; Realidad Virtual; Inmersión; Presencia; Emociones; Neurociencia; Neurocinemática

1. Introduction

Advances in the technology used for physiological exploration of the brain, its greater accessibility and decreased costs have expanded the possibilities of research in areas and applications beyond the strictly medical. In this context, neurocinematics emerged as a novel area of study that merges two disciplines that, for the most part, are not directly related but that, when combined, offer valuable perspectives: cognitive neuroscience and film studies (Hasson *et al.*, 2008).

In recent years, thanks to the appearance and development of new information technologies, a broader panorama has opened up in the investigation of how technological evolution affects the viewer's experience. Among these technologies we highlight virtual reality (VR), augmented reality (AR) and mixed reality (MR) (Slobounov *et al.*, 2014; He *et al.*, 2018; Hofmann *et al.*, 2021). Virtual reality immerses users in completely digital and three-dimensional environments, while augmented reality superimposes digital elements on the real world through devices such as smartphones or special glasses. On the other hand, mixed reality combines real-world elements with digital elements in a more integrated way.

This text presents a methodology that focuses on the detailed description of the physiological effects on the brain as a result of the use of VR, AR and MRI through a technique widely used in neuroscience called electroencephalogram (EEG). The goal is to understand how exposure to these forms of technology influences brain functioning.

In our methodology we use users of these technologies to obtain information on brain activation through EEG as a result of the exchange of electrical signals in the brain. These signals reflect the neurophysiological modifications that take place during cognitive processes and provide a solid and reliable basis for detailed investigation of how information processing is carried out in the human brain (Cha *et al.*, 2015).

We find these signals present in different situations, such as attention, sensory perception, emotional responses, movement, decision making and judgment (Tian *et al.*, 2022). All of these are processes that underlie our relationship with the consumption of content on virtual reality devices. By recording and analyzing these signals and identifying the areas of the brain where greater brain activity is recognized in each user, scientists can unravel the mysteries of how the human brain operates in various situations and cognitive contexts (Dmochowski *et al.*, 2012). This multidisciplinary approach, between neuroscience, engineering and audiovisual communication, allows for a deeper understanding of the human mind and how it relates to the world around us. In addition, it provides a solid basis for the development of medical research, in fields such as psychology, neuroscience and psychiatry, for the treatment of mental disorders and cognitive improvement (Gallese & Guerra, 2022). Through therapies, people's quality of life can be improved and progress can be made in understanding complex issues related to cognition and brain functioning (García López *et al.*, 2022). Likewise, these investigations can have a significant impact on media and entertainment studies, and on studies with industrial objectives, applying the experience of the participants to neuromarketing (Golnar-Nik *et al.*, 2019),

To carry out this methodology, variables from the concepts of "immersion" and "presence" will be used. We refer to immersion as the result of the use of the technological elements used to be absorbed in a digital environment. The degree of immersion will be determined by the quantity and characteristics of these. The most common currently are VR headsets, VR glasses or viewers, speakers and motion controllers (Diemer *et al.*, 2015). The use of immersion is decisive to produce greater presence. Presence relates to the user's feeling that they are really present in that artificial digital environment. This feeling of presence causes cognitive states very similar to reality, and is associated with stronger behavioral reactions (Slobounov *et al.*, 2014), thus favoring the cognitive responses of the subjects and therefore providing a higher quality of the studies to which they are based. through this methodology.

Immersion and presence are fundamental concepts to understand how VR, AR and MR technologies can influence the perception and response of the brain through actions and emotions, and represent a starting point of great interest to understand these new media of communication.

2. State of the matter

2.1. Background

Since the beginning of the 21st century, virtual reality technology has advanced enormously, as has the development of studies focused on the emotions it provokes. The 2020s, meanwhile, could mark a period in which this field reaches a more advanced level of maturity and development. In our search, we have identified several publications that have achieved significant results when using the electroencephalogram (EEG) as a research avenue (Andreu-Sánchez & Martín-Pascual, 2021; Christoforou *et al.*, 2015; Dmochowski *et al.*, 2012; Smith , 2022). Electroencephalography, widely used in the field of neurocinematics, is still used to a much lesser extent in studies linked to the use of VR.

2.2. Justification of the research

Although applied virtual reality has been used in research in different areas since the 1990s, it has experienced an increase in popularity in scientific and commercial contexts in recent years, apart from continuing its more general applications until now that include games. , training, health, marketing and communications. This increase is largely based on the development of a new generation of head-mounted displays or virtual reality glasses (Marín-Morales *et al.*, 2020). This development in technology has greatly helped to expand the use of these devices, improving both their quality and comfort and reducing sales prices.

Until a few years ago, most studies evaluating people's experiences with virtual reality were primarily based on subjective reports provided by the participants themselves (Jalal & Murroni, 2020). However, it has been recognized that these subjective reports could be enriched if they were complemented with neuroscientific research that analyzes the effects of VR at a cognitive level (Smith, 2022). This would allow the new findings to be compared with the conclusions obtained through psychological research and cultural studies (Moreno-Sánchez & Segura, 2020). This integration of approaches may contribute to strengthening the conclusions and raising the level of evidence.

2.3. Research contributions

EEG analysis of brain behavior has been demonstrated as a highly effective study approach to associate perception, stimulus, attention, and emotion in remarkable correspondence with arousing content (Dmochowski et al., 2012; Gautham Krishna et al., 2017). In our methodology immersive virtual reality technologies, such as augmented reality and mixed reality, allow experiment participants to immerse themselves in dynamic and interactive environments that have been specifically designed for a particular research purpose, with a singular and precise intentionality from which conclusions can then be drawn after evaluating the brain map produced by the EEG. This provides researchers with a valuable resource to explore and study human emotions under controlled laboratory conditions (Hofmann et al., 2021). And, in addition, these interactive stimuli allow subjects to actively intervene in the scene, which opens up the possibility of recognizing emotional states during interactive tasks.

In the neurokinematic approach, experiments are based solely on the cinematic experience and only two-dimensional displays are involved. These displays are not considered immersive devices and do not elicit as high a level of immersion and presence in subjects compared to VR. Therefore, it is not as effective an approach as VR for analyzing viewers' emotions (Marín-Morales et al., 2020). When the brain is stimulated with VR, it is logical to think that it tries to give meaning and coherence to that environment by employing the same cognitive processes and perceptual mechanisms that are used when interacting with the real world. This assumption is founded on the notion that the cognitive and perceptual processes that guide understanding and interaction with the environment are fundamental and shared in human experience in general (Seth et al., 2012; Diemer et al., 2015). We do not for this reason find particular risk of bias in experiments in this regard.

We believe that, within academia, the study of how people apply these cognitive processes in the context of virtual reality is of great relevance. Contributions based on an understanding of how the process between perception of virtual reality and interaction with it is effected can provide valuable insights into how cognitive processes work and how they adapt to new technological contexts (Seth et al., 2012).

2.4. Objectives

The objective of this methodology is to classify the results of anatomical maps of the brain based on the electrical signals of brain activity. Next, extract from this analysis the level of presence and emotional arousal for specific circumstances. To get closer to our objectives, the proposed methodology will be applied to a study of brain behavior at different levels of virtual immersion (García López *et al.*, 2022; Lucia *et al.*, 2020).

3.Methodology

During the process, data is recorded and stored in the form of computer, electrical and neuroimaging records, which may be used for other research purposes. The objective of this test is to assess neurofunctional activity through EEG-evoked potentials through the application of passive visual, auditory and tactile stimuli on a vest. The test will consist of a recording during several tests, in which the subject will have to pay attention to the set of stimuli.

The participants in the experiment are part of a voluntary recruitment among Audiovisual Communication and Medicine students at the Complutense University of Madrid, and without including any guidance in the selection. In an initial state we will not give priority to making a specific participation selection since the brain of a person today is very similar to that of Homo sapiens from the Paleolithic (Moreno-Sánchez & Segura, 2020). From this point we have decided to convey the information about the study to our students so that they themselves can volunteer.

The experiment is carried out in a room that is completely isolated from any external stimuli, such as noises or lights. In this way we limit as much as possible any variable that could induce a noise signal in the electroencephalogram results due to involuntary stimulation external to the experiment. Inside this room, we find only a sofa, a television, Oculus Quest 2 model virtual reality glasses and speakers. This room has been specifically designed for carrying out electroencephalogram (EEG) experiments and is located inside a laboratory at the Faculty of Medicine of the Complutense University of Madrid.

Prior to the corresponding consent, the joint controllers will process the personal data for the preparation of the study and execution of the Research Project. The following will be collected: name, surname, sex, age, DNI/CIF/Identification document, academic data (level of education), personal data of the holders of parental authority or guardianship, as well as contact information for them (telephone numbers, emails). electronic). Likewise, the participants declare that they do not have phobias, mental and/or eating disorders or psychiatric and/or neurological pathologies, and that they do not come to the study under the effects of psychotropic substances.

We placed the electroencephalography (EEG) device on each participant's head and the virtual reality glasses. Then, we establish connection with two laptop computers located outside the cabin.

We use the first laptop to synchronize, using our own software and with an internal Wi-Fi network, the virtual reality glasses with the videos launched from the computer and thus start the content. The second laptop is used to record each viewer's brain activity from the EEG device sensors, using ATI Pentatek software.

After completing the EEG recording, we conducted a questionnaire with each viewer to inquire about the emotions they experienced. This questionnaire is based on the questions of the SAM test (Lang, 1985; Barrett *et al.*, 2007; Geethanjali *et al.*, 2017; Zhao *et al.*, 2018). Each participant provides an individual evaluation of her emotional experience during viewing each sequence on a 5-point scale. They evaluate valence (where 5 represents a pleasant experience and 1 unpleasant), relaxation (where 5 indicates a very stressful experience and 1 very relaxing), and the feeling of presence (where 5 suggests a weak feeling and 1 very strong). The total responses are analyzed through Google Forms to subtract the statistics and averages of the total number of respondents.

The experiment currently takes around 60 minutes per participant, including setting up the EEG equipment, playing and recording the Virtual Reality sequences, and administering the questionnaires. No financial compensation is provided to participants for their participation in the study.

In the current EEG recording process, we use a Neuroscan headset with 64 channels and ATI Pentatek software. Before starting the EEG recording, we verified that the electrode impedances are below 5 KΩ. This verification allows us to ensure that there is no interference from atmospheric noise in the EEG recordings.

After completing the registrations of all participants, we proceed to perform a cleaning of the collected data. We also eliminate any occasional electromagnetic interference, such as electricity spikes, to ensure data quality.

At this point we will proceed to data analysis. To identify the areas of the brain where greater brain activity is recorded in each viewer, we use the technique known as LORETA (Low Resolution Electromagnetic Tomography) (Pascual-Marqui *et al.*, 1994). We selected a time window of 200 milliseconds (ms) for each marker recorded in each participant and in each condition (positive sequence and negative sequence). In other words, every time the content director indicated a marker, we took the first 200 ms for analysis, since previous research (Ortiz-Alonso *et al.*, 2015; Lucia *et al.*, 2020) has shown that this interval It is suitable for studying emotional processes during viewing audiovisual content.

Using the LORETA data, we performed global averaging across all participants using IS Media software. We calculate a global average for both the data from a positive sequence and the data from the sequence related to content that provokes fear or suspense. In this way, we obtained two representations. One of them shows the average brain activity of the viewers while viewing the sequence with positive emotional content, and the other during the sequence with negative emotional content (Pascual-Marqui *et al.*, 1994).

We then used the Montreal Neurological Institute (MNI) anatomical brain maps (Evans *et al.*, 1993) to identify the areas of the brain where the greatest brain activity was recorded. As a result of this process, we obtained three-dimensional coordinates (X, Y, Z) that represent the locations in the brain where viewers' average brain activity was concentrated. This procedure was carried out for both the results of the sequence with positive emotional content and for the sequence with negative emotional content.

Finally, we conducted a statistical analysis to assess significant differences between the two conditions. We used Hotelling's T2 test for related groups (Carbonell *et al.*, 2004). Once the results of the Hotelling T2 test were obtained, we again used the Neuronic software to visualize this data. In this case, we generated a representation that allows us to identify the areas of the brain where the greatest differences were observed between viewers during viewing the sequence with positive emotional content and the sequence with negative emotional content.

4. Discussion

4.1. Interpretation of results

Despite achieving a high degree of presence in VR, the results on the analysis of emotions are more difficult to interpret. It must be taken into account that the involvement of a viewer's attention and emotion is conditional on the cortical processing of external stimuli being modulated by cognitive states, that is, it depends on the emotional state (Im *et al.*, 2015). Furthermore, the neural activity of a less attentive viewer will have less extrinsic response and greater intrinsic response (or noise), which will also be reflected in the EEG (Dmochowski *et al.*, 2012). We therefore consider this question as a future path of research: whether this will also be the case in the virtual reality user, or whether it will be compensated by their greater degree of immersion. To resolve this issue, in future studies, it should be differentiated as precisely as possible, on the one hand, cognitive presence (presence as a subjective and personal judgment) and emotional presence (linked to content more or less related to the user). On the other hand, evaluate the role of immersion. This will help us find out what degree of the feeling of presence is due to the immersion or the content being used. And within the analysis of the emotions that have been provoked in the user, define arousal (as a dimension of emotion), and isolate specific emotions (also along the dimensions of arousal and valence). In this way we will be able to identify at what specific moment greater brain activation occurs (Tian *et al.*, 2022).

4.2. Conclusions

The results of several investigations carried out through EEG demonstrate that fully immersive virtual reality induced a greater sense of presence, which implies greater engagement of brain activity with the content (Tian *et al.*, 2022). And along with this, a higher success rate of spatial navigation compared to 2D images. (Slobounov *et al.*, 2014; Tian *et al.*, 2022; Cheng *et al.*, 2023).

5. Future challenges and limitations

We propose an experiment using content focused on generating a feeling of fear (at a level well below terror) or suspense. We choose these to be the predominant emotions since it has been shown that, thanks to their emotional power, they are an effective formula within neurokinematics studies to evaluate the relationship between stimulus and perception. This greater attention and emotional activation allows for greater action potentials between neurons and therefore results in better quality of EEG studies. Although content with this theme strictly would not be essential, it has been shown that negative emotions have a greater impact on the higher cognitive areas of the brain where the EEG is especially sensitive (Khosravi Khorashad & Khosrowabadi, 2022; Tian *et al.*, 2022; Wang & Wang, 2020).

The ideal sample size for a scientific experiment involving electroencephalography (EEG) and virtual reality can vary depending on several factors, such as the specific nature of the research, the objectives of the study, the expected variability in the data, and the desired statistical power. However, providing a specific sample size without knowing more precise details about the experimental design and research objectives would be speculative.

We found several paths for improvement in our methodology that we hope will be improved as the advancement of technology and our accessibility allow it. Leveraging virtual reality in more naturalistic research designs requires the creation of high-quality virtual reality content, more complex technical configurations, and resolving the discomfort caused by immersive devices (Hofmann *et al.*, 2021). To foster the degree of presence and enhance the VR experience, the future inclusion of realistic and responsive avatars will help increase understanding of the emotions evoked during social interactions and the associated physiological responses (Marín-Morales *et al.*, 2020).

Another proposal for improvement consists of incorporating technologies such as functional magnetic resonance imaging in the same experiment to have equivalent quality results in terms of both temporal and spatial brain response (Cha *et al.*, 2015). It is also common to use eye tracking along with other cognitive neuroscience technologies, such as the electrical conductance of the skin, so that all this together corroborates theoretical studies.

Until 2023, very few of the studies used machine learning algorithms to classify the analyzed emotions. In experiments with many subjects, this technology we believe will facilitate the classification of the results, as has already been demonstrated in some pioneering research using a machine learning algorithm to recognize emotional states (Marín-Morales *et al.*, 2020). Likewise, it would be interesting to open a research avenue in which to contemplate how the results influence both the effect of novelty and a user trained in these technologies and their evolution.

Future research challenges will feature the continued progress of technology, leading to a hypothetical scenario where artificial intelligence can play a revolutionary role. This possibility suggests that artificial intelligence will be able to capture and recognize our thoughts, and interpret our emotions and feelings. This advance would have significant implications for the field of Brain-Computer Interface (BCI), establishing direct communication between our brain and a computer, to greatly improve people's ability to control devices and participate in virtual environments using brain signals as a medium. Communication.

One of the most fascinating projections of this technological evolution is the possibility of realizing technologically mediated telepathy. In this scenario, the ability of artificial intelligence to understand and transmit thoughts and emotions could pave the way for direct communication between individuals, or even with other artificial intelligences. This emerging paradigm not only represents a technical advance, but also poses ethical and philosophical challenges. Consideration of the privacy, security and social implications of such a level of mind-machine connection will be crucial as this technology evolves.

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