Ingeniería y Competitividad
Vol 27 (2) 2025 doi: 10.25100/iyc.v27i2.14737

Vol 27 (2)

ISSN
0123-3033
e- 2027-8284

Original Article

The sense of presence in virtual environments: an analysis based on EEG, ECG, and GSR signals

La sensación de presencia en entornos virtuales: un análisis basado en señales EEG, ECG y GSR

Víctor A Ortiz-Bravo[1] Walter Serna Serna[2] Marisol Jiménez Gallego[2]
Juan Pablo Trujillo Lemus[2] Angie Correa Acosta[2]

[1] Universidad Uniminuto Pereira. Risaralda, Colombia.
[2] Universidad Tecnológica de Pereira. Risaralda, Colombia.

How to cite?

Ortiz-Bravo VA, Serna W, Jiménez G, Trujillo JP, Correa A. The sense of presence in virtual environments: an analysis based on EEG, ECG, and GSR signals. Ingeniería y Competitividad, 2025 27;(2):e-21314737

https://doi.org/10.25100/iyc.v27i2.14737

Received: 9-02-25
Evaluated: 19-03-25
Acepted: 29-09-25
Online: 10-10-25

Correspondence

bravo.ortiz@uniminuto.edu.co

Abstract

Introduction: the sense of presence refers to the subjective experience of being immersed in a virtual or simulated environment. These sensations can be objectively assessed using electrophysiological signals such as electroencephalography (EEG), electrocardiography (ECG), and galvanic skin response (GSR). However, psychological characteristics also significantly influence the degree of presence experienced in virtual environments.
Objectives: this study proposes a methodology for quantifying the sense of presence during immersion in virtual environments by combining multiple electrophysiological features validated by current scientific literature.
Methodology: a total of 14 virtual experiences related to tourist locations in the Magdalena region of Colombia were evaluated. These experiences were segmented into 20-second time windows, during which EEG, ECG, and GSR signals were recorded. Each virtual scenario was evaluated six times by different users, yielding 84 biosignal recordings. From each recording, six presence-related indicators were extracted. Additionally, users were classified as either High or Low in their psychological capacity to engage with the experience, based on a qualitative assessment involving five presence indicators.
Results: users with a high engagement capacity experienced a sense of presence in 15% more of the virtual environments compared to users with low engagement capacity.
Conclusions: the findings support that a user's sense of presence in a virtual environment is not solely determined by the level of virtual reality immersion but is also influenced by psychological profile and prior experience with immersive technologies.

Keywords: Electrophysiology, immersion, signal processing, virtual reality, sense of presence

Spanish version

Resumen

Introducción: el sentido de presencia se refiere a la experiencia subjetiva de estar inmerso en un entorno virtual o simulado. Estas sensaciones pueden evaluarse objetivamente mediante señales electrofisiológicas como la electroencefalografía (EEG), la electrocardiografía (ECG) y la respuesta galvánica de la piel (GSR). Sin embargo, existe evidencia que indica que las características psicológicas influyen significativamente en el grado de presencia experimentado en entornos virtuales.
Objetivos: este estudio propone una metodología para cuantificar el sentido de presencia durante la inmersión en entornos virtuales, combinando múltiples características electrofisiológicas validadas por la literatura científica actual.
Metodología: se evaluaron un total de 14 experiencias virtuales relacionadas con sitios turísticos del departamento del Magdalena, Colombia. Estas experiencias se segmentaron en ventanas de tiempo de 20 segundos, durante las cuales se registraron señales EEG, ECG y GSR. Cada escenario virtual fue evaluado seis veces por diferentes usuarios, obteniéndose 84 registros de bioseñales. De cada registro se extrajeron seis indicadores relacionados con la presencia. Además, los usuarios fueron clasificados como de alta o baja capacidad psicológica de involucramiento, según una evaluación cualitativa basada en cinco indicadores de presencia.
Resultados: los usuarios con alta capacidad de involucramiento experimentaron un sentido de presencia en un 15% más de los entornos virtuales en comparación con los usuarios con baja capacidad de involucramiento.
Conclusiones: los resultados respaldan que el sentido de presencia en un entorno virtual no depende únicamente del nivel de inmersión de la realidad virtual, sino también del perfil psicológico del usuario y su experiencia previa con tecnologías inmersivas.

Palabras clave: Electrofisiología, inmersión, procesamiento de señales, realidad virtual, sensación de presencia.

Why was this study conducted?

The development of a neuroscientific evaluation project on the sense of presence during immersion in virtual environments responds to the need to understand, from an objective and evidence-based perspective, how the brain and nervous system react to the multisensory stimuli that characterize Virtual Reality experiences.

Most studies on usability and immersion in these types of environments are based on users' self-reported subjective perceptions; however, these approaches do not accurately reflect the cognitive processes that determine the actual quality of the experience. This project aims to integrate neuroscience with the design of immersive technologies, providing a scientifically validated methodology to measure the cognitive impact of virtual environments.

What were the most relevant findings?

The most relevant results of the study show a statistically significant difference in the levels of sense of presence between participants with high and low immersive capacity. Likewise, the integration of six physiological indices derived from EEG, ECG, and GSR allowed for highly accurate differentiation of the sense of presence state, revealing a direct correspondence between neurophysiological responses and participants' self-perceptions. Moreover, coherence was observed between physiological patterns and psychological profiles, indicating that individuals with a greater ability to become emotionally and cognitively engaged in the virtual experience tend to more easily activate the sense of presence.

What do these findings contribute?

These findings provide strong evidence supporting the use of neurophysiological biomarkers as an objective measure of the sense of presence, offering a reliable alternative to traditional self-report-based methods, which are often susceptible to subjective bias. Additionally, this study validates the feasibility of a multimodal approach that combines EEG, ECG, and GSR to assess the sense of presence in virtual environments, demonstrating that the interaction between users' physiological and psychological characteristics plays a key role in the quality of the virtual experience.nance operating environment. This contributes to compliance with high quality standards, resource optimization, and process efficiency, which, in turn, strengthens the railway company's overall performance and its ability to offer more reliable and safe services.

doi: 10.25100/iyc.v27i2.14737

Introduction

In recent years, virtual reality (VR) has emerged as a promising technology with applications in various areas, such as entertainment, tourism, education, health, among many others. To achieve an immersive and convincing experience, where the user experiences a sense of presence and is immersed in VR as if they were physically present, it is essential to understand and evaluate the sense of presence experienced by users, in order to create the illusion of being present in a virtual world (1). The subjective feeling of being present in a virtual environment absorbed by what is happening in the real world, known as the sense of presence, is a key aspect in determining the effectiveness and quality of the virtual experience (2). While the quality of virtual content generates greater immersion, the sense of presence is unique to each individual. Despite this, there are no methodologies that perform psychological profiling and user experience profiling with virtual reality technology to determine the implications for the sense of presence.

Additionally, the evaluation of the sense of presence and the level of immersion in VR has been the subject of study in the scientific community. Traditionally, the evaluation of the sense of presence generated by virtual environments is carried out by completing questionnaires to answer this question. However, this methodology only allows for the measurement of the user's conscious response (3); this type of evaluation methodology can present multiple difficulties, given the possibility of producing biased responses at will or due to cultural, socioeconomic, religious, or other characteristics. Given the above, there is a need to evaluate VR environments beyond conscious responses, with a quantitative approach and at a subconscious level of what virtual environments generate in users. In this context, the use of electrophysiological signals has emerged as a promising tool for objectively measuring the electrophysiological response of users during interaction in virtual environments and, in this way, determining whether a user's psychological profile affects their sense of presence in a virtual environment.

In this work, we propose to analyze electrophysiological signals as tools for the objective evaluation of the sense of presence and its correspondence with the psychological profiling of a user during an experience in VR environments.

Materials and methods

In this section, important concepts for the reader will be detailed and the methodology used to conduct this research will be analyzed. The process was developed in several stages: first, a survey was designed and administered to obtain the psychological profile of the user in terms of their ability to engage in a virtual experience. In a second stage, the electrophysiological responses were recorded during VR immersion processes. Third, the acquired signals were adapted and preprocessed. In the fourth stage, six quantitative indices of the preprocessed data for sense of presence were obtained, selected, and validated in previous external research. Finally, an absolute frequency process was performed based on the number of indices, discriminating between participants with high and low sense of presence, as shown in the results section.

doi: 10.25100/iyc.v27i2.14737

Psychological profile of participants

There are different types of virtual consumers that are determined by psychological variables such as personality traits, motivations, and attitudes (5) and that determine their choices regarding the use of digital technology. These psychological variables must be taken into account in the design of virtual scenarios as they can influence users' sense of presence.

Some research has found that personality traits are associated with the perspective that consumers take in an interaction with VR (6). Along the same lines of research, direct relationships have been found between certain psychological measures and the level of presence in immersive VR, reflecting that absorption capacity, dissociation, and locus of control are psychological traits that are directly proportional to the sense of presence (7). On the other hand, other studies have found that the feeling of control, the capacity for enjoyment, and curiosity are personal traits that drive users' sense of presence in VR environments (8).

Certain psychological variables of users can also be modified after experiences in virtual environments (9), even modifying subjective pain experiences (10) or enhancing creative skills in shopping scenarios (11), which again demonstrates the bidirectional interrelationship between psychological measures and the sense of presence in virtual scenarios.

Finally, the relationship between human behavior patterns and their influence on interaction with virtual technologies has become a field of interest that must be considered in VR design (12). This psychological profiling will allow us to establish a priori the subject's ability to generate states of sense of presence when faced with virtual content.

Sense of presence

This is a cognitive process that involves the subjective perception of being present in a virtual environment, which leads to the interpretation and cognitive processing of the sensory information received. When a user experiences a sense of presence in a VR environment, they are constructing a mental representation of being physically present in that simulated environment. This cognitive process involves the integration of visual, auditory, and tactile information, as well as the interpretation and assimilation of interactions and stimuli present in the virtual environment (1).

In addition, the sense of presence is also related to other cognitive processes, such as attention, memory, and spatial perception. The user's attention is directed toward the virtual environment, which involves selecting and processing information relevant to the immersive experience. On the other hand, the memory is responsible for storing and retrieving information from the virtual environment, allowing for continuity and consistency in the experience. Spatial perception is involved in interpreting location and movement in the virtual environment, contributing to the feeling of actually being present in a VR environment.

doi: 10.25100/iyc.v27i2.14737

Electrophysiological measures

Below is a brief description of the main electrophysiological variables that will be used for the quantitative analysis of VR content.

Electrocardiography (ECG)

The project proposes the use of electrocardiographic signals, as these are one of the signals that provide the most real-time information about a person's emotional states. These signals provide information on both the emotional state and its intensity (18), (19). Specifically, the aim is to measure heart rate variability (HRV), which evaluates fluctuations in the time intervals between heartbeats, in order to measure the states of stress associated with immersion in virtual environments, as HRV provides important information about how the body responds and adapts to episodes of stress.

Galvanic skin response (GSR)

Galvanic skin response (GSR) is the measurement of variations in sweat activity and the electrical behavior of the skin (20). This activity responds to external and internal stimuli and is associated with emotional and cognitive states (21), making it possible to detect changes in a person's emotional and cognitive activity generated by the virtual reality environments presented.

The e-Health Sensor platform will be used to acquire the electrocardiographic signal and galvanic skin response. This device allows biometric and medical applications to be carried out using Arduino and Raspberry Pi.

Electroencephalography (EEG)

The electroencephalographic signal (EEG) is the recording of electrical activity originating in the brain. This recording is obtained by implanting electrodes in the brain or placing electrodes on the scalp (surface electroencephalography, sEEG). This electrical activity is generated continuously in the brain due to thoughts, activities, and almost every action performed by humans. EEG analysis considers many characteristics to find morphological patterns or unexpected disturbances that could lead to the discovery of anomalies, pathological compromise, or interpretation of functional behaviors and cognitive performance. We will work with the temporal, frequency, and spatial analysis of EEG signals, using state-of-the-art indices as direct indicators of the sense of presence, based mainly on the powers of the brain bands and electrical activities in specific areas of the brain directly related to cognitive processes of interest for the object of study.

To capture EEG signals, OpenBCI equipment will be used as a brain-computer interface. This is an open hardware device with 16 differential input channels, compatible with active and passive electrodes, based on Arduino technology capable of acquiring brain electrical activity at a sampling rate of 125 or 250 Hz with 24-bit resolution and Bluetooth communication to the computer.

Experimental design

This study has a quantitative, exploratory, and experimental approach and was conducted in accordance with the ethical standards approved by the bioethics committee of the University of

doi: 10.25100/iyc.v27i2.14737

Magdalena; all participants signed an informed consent form prior to their participation. In terms of the profiling of the study subjects, two types of a priori sense of presence in virtual environments were categorized as high and low. An open invitation was extended to 100 people to complete two digital forms. This process involved subjects of equal gender, with an average age of 32 ± 15 years, and their data was treated under confidentiality parameters. The surveys were designed with the help of an expert neuropsychologist with in-depth knowledge of the topic and validated by experts in virtual reality. The first form generated a sociodemographic profile of the user in order to collect social, cultural, and emotional characteristics resulting from the social context that the person has built, with the aim of determining how sociocultural characteristics can impact the way subjects make decisions in certain virtual scenarios. Based on the research analyzed in the literature, a second questionnaire was designed with 15 questions evaluated on a Likert scale: almost always, sometimes, and almost never. This allowed for the identification of relevant characteristics to facilitate the sense of presence in virtual environments for users. The psychological traits sought were:

1. Absorption capacity: ability to become involved or immersed in a situation (7), (16).

2. Dissociation capacity: interruption of integrated functions of consciousness involving the ability to “forget” or distance oneself from the real world or move away from one’s environment (7), (9), (13).

3. Extroversion: the ability to engage with stimuli in the environment (14), (15).

4. Locus of control: the extent to which a user believes that events are caused either by their own behavior and actions (internal locus of control) or by external forces such as fate, chance, luck, or coincidence (16).

5. Beliefs and meanings in virtual environments: concept that a user assigns to the virtual experience and that gives the experience greater or lesser meaning and significance (17).

This process categorized the different users, discarding those with intermediate ratings and leaving a database of 63 potential evaluators of the experiences. However, due to the imbalance between the user categories and their availability for testing, we sought to ensure that each of the virtual scenarios was evaluated by three high-capacity users and three low-capacity users in terms of presence. Given that we worked with consolidated state-of-the-art indicators, a large sample size was not required to explore new relationships, but rather a sufficient number of cases to validate the proposed methodology for integrating EEG, ECG, and GSR signals under controlled conditions.

Description of virtual content

Within the framework of the AvenHub Magdalena project “Strengthening the adventure tourism offer through technological development in the department of Magdalena,” managed and executed by the company Innovanex, 14 virtual environments were built in different locations of interest (see Figure 1). The script for each virtual environment includes multiple tourist activities, which correspond to the main attractions of each municipality in the department of Magdalena.

doi: 10.25100/iyc.v27i2.14737

All virtual environments were developed using the Unity 3D real-time rendering engine, employing the C# programming language. The display was configured at a resolution of 1440x1600 pixels per eye. In addition, all three-dimensional models were designed with the open source software Blender.

Figure 1. Example of different virtual environments evaluated. **Source:** Authors

Capture of electrophysiological signals

To evaluate the VR environments, the following experimental setup was used, detailing the processes undergone by the evaluation users, based on the proposal for electrophysiological data collection designed by (22). Each virtual environment, one per municipality, with different tourist locations in Magdalena, was evaluated by three users with low and three with high psychological sense of presence. To capture electrophysiological data during the virtual reality experience, the user wore Oculus Quest 2 virtual reality glasses, with an automatic and guided tour for each virtual environment, which did not involve physical movement. Each of the electrophysiological signals acquired were divided into 20-second windows, responding to both physiological and methodological criteria, since a 20-second interval is sufficient to capture stable physiological responses to sensory stimuli in the three biosignals and allows for an adequate balance between temporal resolution and stability of the extracted indicators. This allows for a more specific analysis of the electrophysiological response at segmented moments in the virtual environments, as each of the 14 virtual environments had different durations ranging from 2 to 10 minutes.

One of the priorities in the application of the experiment was to ensure the synchronization of cardiac, electrodermal, and brain data collection with the projection of stimuli (virtual environments). To this end, it was proposed to include a few seconds of a blank screen in the VR content to identify the start time of the signals acquired from an initiation tone. This process also allows filtering by baseline correction in a resting state before the stimulus is projected.

Once the user signed and declared their consent to participate in the tests in writing, the proposed methodology was applied. The user had to be seated, trying to move as little as possible to avoid adding noise and artifacts to the acquired signals. Initially, they were asked to close their eyes and were told to open them when they heard a distinctive sound to ensure the synchronization of the visualization of the environments and data acquisition.

doi: 10.25100/iyc.v27i2.14737

In the case of electrocardiographic recordings, lead I was used according to Einthoven's triangle, which defines the axes of the electrocardiographic signal (ECG) leads in the frontal plane. Two electrodes were placed near the user's shoulders and a third electrode, serving as a reference, was placed on the left side of the lower abdomen.

In the case of GSR signals, a connection was made to the index and middle fingers to measure electrical impedance. In this case, it is necessary to ask the user to relax for two minutes in order to establish a baseline for measurement, during which time no physical or emotional disturbances are expected.

Following the methodology presented by Baka et al. (23), the locations of the 10-20 system were prioritized as follows: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4 referenced in A1 (ear lobes). An impedance below 5 KΩ and a sampling frequency of 125 Hz were sought. Preliminary tests were carried out to ensure the correct acquisition of each of the channels.

Figure 2 shows the devices used to acquire the EEG signals (cap with electrodes on the head), ECG (electrodes placed on the lower part of the clavicles and lower abdomen on the left), and GSR (electrodes on the index and ring fingers of the left hand), as well as the VR projection glasses.

Figure 2. Acquisition of electrophysiological signals. **Source:** Authors

Signal conditioning and preprocessing

Given the nature of electrophysiological signals, these signals are affected by muscle and eye artifacts, electrode movement, electrical noise, baseline drift, and other noises. Because of this, a filtering phase is necessary as signal preprocessing (24, 25, 26). To solve this problem, we use a 5th order Butterworth bandpass digital filter. This filter has the best ratio between attenuation and phase response. It has no ripple in the passband or stopband, and because of this, it is known as a maximally flat filter. The cutoff frequencies used are (0.5 Hz – 50 Hz) for EEG, ECG, and GSR cases. These bands are located according to the standards of the American Health Association (AHA) (27). These cutoff frequencies allow the elimination of mechanical noise generated by electrode movement and muscle movements. Additionally, to eliminate trend lines, a time windowing

doi: 10.25100/iyc.v27i2.14737

technique was used and the average value corresponding to each window was removed. For atypical data, a Hampel filter was implemented.

In the case of EEG, once the recording was free of artifacts that could alter the results of the analysis, the waves were classified according to their frequency into five main bands: delta (0.5 Hz - 4 Hz), theta (4 Hz - 8 Hz), alpha (8 Hz - 12 Hz), beta (12 Hz - 30 Hz), and gamma (30 Hz - 50 Hz). For this, a 5th order Butterworth bandpass digital filter was used again at the specified frequencies.

Indices for sense of presence

Time-frequency and spatial characteristics were extracted from the EEG signal, which, according to previous research, are directly related to the increase in the sense of presence and its main correlates. This was demonstrated in previous research related to the following:

Index 1: This is the increase in coherence in the beta band between the left temporal lobe and the left occipital lobe (4). For this, the beta band was used in channels T7 and O1, and equation (1) was applied, which relates the brain coherence between two channels (Coh).

$$Coh = \frac{|P_{xy}(w)|^2}{P_x(w)P_y(w)}, \quad (1)$$

where P_{xy} is the power spectral density (PSD) of the channel pairs; P_x and P_y are the power densities of each channel; this is calculated for each frequency bin and, finally, the mean value of the coherence vector is calculated.

Index 2: It has been determined that power increases in the theta band in the occipital lobe determine an increase in the sense of presence (4). For this implementation, the short-time Fourier transform (STFT) with a Kaiser window with L=125 and beta=5 was used to calculate the PSD in each of the windows generated from channels O1 and O2 and adding their mean values.
Index 3: It has been shown that the increase in total power (1-50 Hz) in the frontal lobe is a good indicator of sense of presence (4). To implement this point, the short-time Fourier transform (STFT) was used again with a Kaiser window with L=125 and beta=5, specifically in the front channels: AF3, F7, F3, F4, F8, AF4. Their PSD was calculated and their average values were added by time windows.

These first three sense-of-presence indices were compared against the same reference measurement at the start of the test, since the sense-of-presence process is not instantaneous and requires some time for the user to reach this state.

Index 4: Research conducted by (28) indicates the decreased participation of the right dorsolateral prefrontal cortex (DLPFC) and, to a lesser extent, the left DLPFC at high frequencies as highly specific neural correlations for the orchestration of the presence experience in adults. These results were supported by another study by the same authors (29). Given the above, brain mapping was performed from the temporal signal acquired using the SMP12 toolbox, which finds the solution to the inverse problem. This solution allows the electrical activation to be visualized in a 3D model of the brain using a color map. After this, visual monitoring of the activation in the brain model of the

doi: 10.25100/iyc.v27i2.14737

right DLPFC area was performed, verifying the decrease in brain activity and the increase in brain activity in the left DLPFC.

The following indicators were obtained from the ECG and GSR signals:

Index 5: The change in heart rate (HR) was analyzed with respect to the previously recorded baseline activity. The difference between the HR during visual stimulation and the HR at rest was calculated, thus reflecting the increase or decrease in heart rate (30).
Index 6: Galvanic skin response (GSR) activity was examined in relation to baseline activity prior to visual stimulation. Skin conductance was recorded during the experience and compared to reference levels, revealing the presence of variations in galvanic skin response associated with the visual stimulus (31).

Results and discussion

This section shows the different results obtained by applying the methodology described in the previous chapter. The tables, graphs, and data shown belong to a single user in a particular location with a duration of 120 seconds, which was divided into six time windows. This is to illustrate the results individually. However, each of the 14 locations has different durations, and the same methodology was applied to each of the resulting time windows. The results for all users and time windows are summarized in data tables. Finally, the results will be discussed. For indices 1, 2, and 3, the following was obtained: Figure 3 shows the metrics obtained from the time windows into which a virtual experience was divided. The dotted line is the threshold for each of the metrics to be considered high or low and refers to the value of the metric in the base window. A**:** shows the coherence in the beta band in channels T7 and O1, and as can be seen, only time windows 3 and 6 exceed the threshold. B**:** finds the PSD value in the occipital channels O1 and O2 in the Theta band using STFT. In this case, all time windows exceed the threshold, indicating a high sense of presence. C**:** for index 3, the same process described in index 2 is performed, but only on the frontal channels (AF3, AF4, F3, F4, F7, F8) and the full-band signal, i.e., (0.5 Hz - 50 Hz).

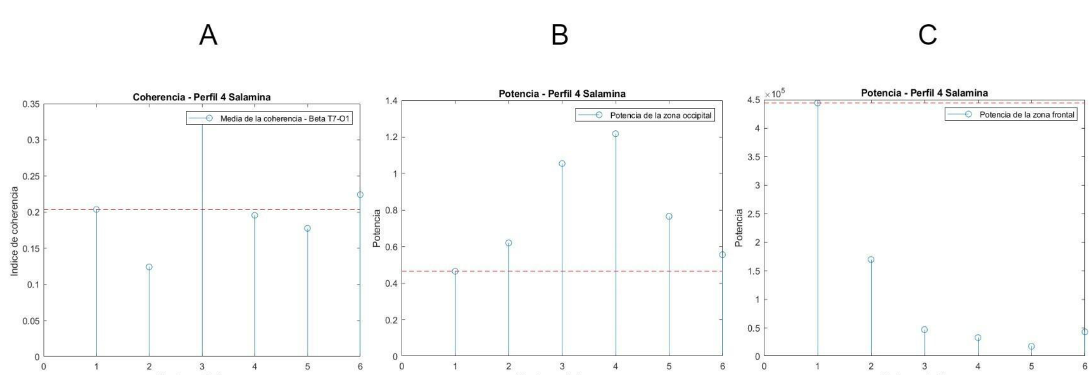

Figure 3. Results of indices 1, 2, and 3 for each time window. **Source:** Authors

In this specific case, no time window was classified as having a high sense of presence. For index 4, the following spatial activation representations were obtained: Figure 4 shows a three-dimensional

doi: 10.25100/iyc.v27i2.14737

representation of brain electrical activity from the captured EEG signal. For this, a brain model with 14 channels per 2004 sources was used, using the SPM12 toolbox and the Multiple Sparse Priors (MSP) inverse problem solution algorithm. A map was generated on a standardized brain model that represents the power of brain activity through color scales, revealing the most likely communication areas and structures at each moment.

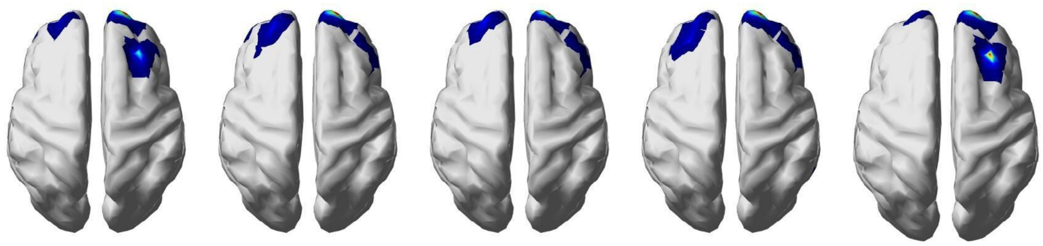

Figure 4. Brain mapping of the signal by time windows. **Source:** Authors

The electrical brain activity was averaged for each time window to obtain a single representation. For indices 5 and 6, Table 1 of results was obtained.

Table 1. Results of ECG and GSR measurements for sense of presence.

Window	base HR	HR	Index 5	base GSR	GSR	Index 6
2	50.64	74.77	-	127,749.758	128,825.23	-
3	50.64	45,367	+	127,749.758	129,191.19	-
4	50.64	49,889	+	127,749.758	129,669.49	-
5	50.64	45,248	+	127,749.758	130,156.05	-
6	50.64	49,167	+	127,749.758	120,212.77	+

Source: Authors

Table 1, index 5, shows an increase or decrease in heart rate relative to baseline activity, indicated by the symbols “+” and “-” if the sense of presence increased or decreased in the window. Index 6 evaluated galvanic skin response activity, again showing increases or decreases relative to baseline activity. Table 2 compiles the information from all indices.

Table 2 shows the results for a single user in the six presence indicators evaluated in each time window. This same process was carried out with the six records (three with users with low presence sense and three with users with high presence sense) in each of the 14 virtual reality environments evaluated, each subdivided into time windows.

doi: 10.25100/iyc.v27i2.14737

Table 2. Electrophysiological indices for sense of presence for one user.

	Index 1	Index 2	Index 3	Index 4	Index 5	Index 6	# indexes on the rise
Window 1	Reference base window						
Window 2	low	high	low	low	low	low	1
Window 3	high	high	low	high	low	low	3
Window 4	low	high	low	neutral	high	low	2
Window 5	low	high	low	high	high	low	3
Window 6	high	high	low	low	high	high	4

Source: Authors

From this information, the number of high presence sense indices was calculated, and the information shown in Table 3 was obtained.

Table 3. Count of high indices for the two presence sense capabilities.

	Users with high sense of presence	Users with low sense of presence
Scenario 1		
Window 2	6	4
Window 3	8	7
:	:	:
Window 6	2	7
Scene 2		
Window 1	3	6
:	:	:
Window 14	12	5
Scenario 3		
Window 1	12	5
:	:	:
Window 20	9	7
⇣		
Stage 14		
Window 1	6	10
:	:	:
Window 14	6	10
Window 15	7	10

Source: Authors

Table 3 summarizes the results of all tests performed on all users and virtual environments. The

doi: 10.25100/iyc.v27i2.14737

two categories were considered according to their psychological sense of presence, and a total was calculated by adding the 14 scenarios from 394 time windows. The number of high indices per time window in each category was taken into account.

In Table 4, a count was made in each of the two categories of the number of indicators with a high sense of presence for each of the 394 time windows, taking into account that there were three users in each category for a total of 1182 windows evaluated, each with a maximum of 18 high indicators (six per user). Some representative statistical data were obtained from the two samples, such as the mean value of the number of high presence indicators per window for each category and its respective uncertainty value.

Table 4. Evaluation of sense of presence according to immersive capacity.

Low Presence Users in 1182 windows evaluated		High Presence Users in 1182 windows evaluated	
High indices	255	High indices	3640
Average	6.5	Average	9.3
Deviation	2.1	Deviation	2.5

Source: Authors

The results of the statistical analysis show a significant difference in the mean scores between the groups categorized by presence capability. Specifically, the group with high presence capability obtained a significantly higher mean (M_a= 9.3; SD = 2.5) compared to the group with low capability (M_b= 6.5; SD = 2.1), a difference that was confirmed by a hypothesis test using Student's t-test for independent samples ($t = -29.80$; $p << 0.001$).

The results obtained from the application of the proposed methodology show that the use of electrophysiological signals for the evaluation of sense of presence in virtual reality environments is an objective and reliable alternative to traditional methods based on self-reports. The combination of the six quantitative indices extracted from electroencephalography (EEG), electrocardiography (ECG), and galvanic skin response (GSR) made it possible to establish with high accuracy whether or not participants experienced a sense of presence in the virtual environment. This supports the feasibility of a biomarker-based approach to measuring sense of presence, eliminating the subjectivity inherent in self-administered questionnaires and reducing the bias associated with individual variability in the interpretation of the immersive experience, validating the results obtained in (4) and (28).

One of the most relevant findings is the consistency between physiological indices and the categorization of participants according to their psychological profile. The results suggest that individuals with a greater psychological capacity to engage in an experience tend to activate the sense of presence in VR more easily, which could be related to a lower cognitive load in adapting to the virtual environment, objectively validating the postulate proposed in (7). This finding is consistent with previous research indicating that the experience in virtual reality depends, in part, on factors characteristic of the user with this type of technology.

doi: 10.25100/iyc.v27i2.14737

Despite the contributions of this research, it is important to acknowledge some limitations. First, although the six physiological indices have been validated in previous studies, their combination in a single assessment system requires further generalization in diverse populations with varying levels of familiarity with virtual reality.

Conclusion

The results of this research show that users' immersive capacity directly influences the activation of the sense of presence in virtual reality environments. Participants with a high capacity for engagement in virtual environments showed a greater number of physiological indicators associated with presence (9.3 on average) compared to those with low immersive capacity (6.5 on average), a difference that was confirmed by a hypothesis test using the Student's t-test for independent samples. Furthermore, validation through self-reports showed that users with higher immersive capacity perceived a high sense of presence in 51% of the time windows, while those with low immersive capacity only experienced it in 36%.

These findings reinforce the hypothesis that measuring sense of presence through electrophysiological signals is an objective and reliable approach, reducing dependence on subjective responses. Furthermore, the data obtained in relation to the personality characteristics and psychosocial profile of the study subjects indicate that certain psychological traits may influence the ease with which a person experiences presence in virtual environments, which has important implications for the design of more accessible and immersive experiences.

In conclusion, this study contributes to the understanding of the sense of presence in virtual reality, providing a methodological framework based on biomarkers and particular characteristics of users that can be applied in various areas such as cognitive neuroscience, immersive interface design, and the optimization of experiences in virtual environments.

Acknowledgements

This article is the direct result of research carried out by the scientific team within the framework of the project "Strengthening the Adventure Tourism Offer Through Technological Development in the Department of Magdalena - Avenhub Magdalena identified with code BPIN 2020000100193" funded by Minciencias, through the General Royalties System.

CrediT authorship contribution statement

Conceptualization - Ideas: Victor Ortiz-Bravo, Walter Serna-Serna, Juan Pablo Trujillo-Lemus. Data Curation: Victor Ortiz-Bravo, Marisol Jiménez-Gallego, Angie Correa-Acosta. Formal analysis: Víctor Ortiz-Bravo, Walter Serna-Serna, Marisol Jiménez-Gallego. Acquisition of financing: Juan Pablo Trujillo-Lemus. Investigation: Víctor Ortiz-Bravo, Walter Serna-Serna, Marisol Jiménez-Gallego. Methodology: Víctor Ortiz-Bravo, Walter Serna-Serna, Marisol Jiménez-Gallego. Project Management: Marisol Jiménez-Gallego, Angie Correa-Acosta. Resources: Víctor Ortiz-Bravo, Marisol Jiménez-Gallego, Angie Correa-Acosta. Software: Víctor Ortiz-Bravo

doi: 10.25100/iyc.v27i2.14737

Walter Serna-Serna. Supervision: Victor Ortiz-Bravo, Walter Serna-Serna, Juan Pablo Trujillo-Lemus. Validation: Víctor Ortiz-Bravo, Marisol Jiménez-Gallego. Writing - original draft - Preparation: Víctor Ortiz-Bravo, Marisol Jiménez-Gallego. Writing - revision and editing - Preparation: Víctor Ortiz-Bravo, Marisol Jiménez-Gallego.

Financing: Avenhub Magdalena en el marco del proyecto “Fortalecimiento de la Oferta de Turismo de Aventura a Través de Desarrollo Tecnológico en el Departamento de Magdalena, financiado por Minciencias, a través del Sistema General de Regalías.

Conflict of interest: does not declare. Ethical aspect: does not declare.

References

(1) W. M. Felton and R. E. Jackson, “Presence: A review,” Int. J. Human--Comput. Interaction, vol. 38, no. 1, 2022. https://doi.org/10.1080/10447318.2021.1921368

(2) M. Slater and S. Wilbur, “A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments”, Presence (Camb), vol. 6, no. 6, 1997. doi: https://doi.org/10.1162/pres.1997.6.6.603

(3) M. Kuri S. A. Karre and Y. R. Reddy, “Understanding software quality metrics for virtual reality products - A mapping study”, in En 14th Innov. Softw. Eng. Conf. (Formerly Known as India Softw. Eng. Conf.). https://doi.org/10.1145/3452383.3452391

(4) M. Athif et al, “Using biosignals for objective measurement of presence in virtual reality environments”, Annu. Int. Conf. IEEE Eng. Med. Biol. Soc, 2020. doi: 10.1109/EMBC44109.2020.9176022

(5) M. Á. Gandarillas Solinís and M. Montañés Serrano, “Psychosocial profiles of users of virtual environments: Motivations, behaviors, and consequences,” Univ. Psychol, vol. 18, no. 3, pp. 1–14, 2019. https://doi.org/10.11144/Javeriana.upsy18-3.ppue

(6) A. Katifori C. Lougiakis and M. Roussou, “Exploring the effect of personality traits in VR interaction: The emergent role of perspective-taking in task performance”, Front. Virtual Real, vol. 3, 2016. https://doi.org/10.3389/frvir.2022.860916

(7) C. D. Murray, J. Fox and S. Pettifer, “Absorption, dissociation, locus of control and presence in virtual reality”, Comput. Hum. Behav, vol. 23, no. 3, pp. 1347–1354, 2007. https://doi.org/10.1016/j.chb.2004.12.010.

(8) W. Wei, R. Qi, and L. Zhang, “Effects of virtual reality on theme park visitors’ experience and behaviors: A presence perspective,” Tour. Manag, vol. 71, pp. 282–293, 2019. https://doi.org/10.1016/j.tourman.2018.10.024

(9) F. Aardema, K. O’Connor, S. Côté, and A. Taillon, “Virtual reality induces dissociation and lowers sense of presence in objective reality,” Cyberpsychol. Behav. Soc. Netw, vol. 13, no. 4, pp. 429–435, 2010. https://doi.org/10.1089/cyber.2009.0164

(10) H. G. Hoffman, T. Richards, B. Coda, A. Richards and S. R. Sharar, “He illusion of presence in immersive virtual reality during an fMRI brain scan”, Cyberpsychol. Behav, vol. 6, no. 2, pp. 127–131, 2004. https://doi.org/10.1089/109493103321640310

(11) W. B. Kim and H. O. J. Choo, "How virtual reality shopping experience enhances consumer creativity: The mediating role of perceptual curiosity", SSRN Electron, 2023. https://doi.org/10.1016/j.jbusres.2022.113378

(12) M. Aristeidou, E. Scanlon and M. Sharples, "Profiles of engagement in online communities of citizen science participation", Comput. Hum. Behav., vol. 74, pp. 246–25, 2017. https://doi.org/10.1016/j.chb.2017.04.044

(13) H. S. Wallach, M. P. Safir and R. Samana, "Personality variables and presence", Virtual Real, vol. 14, no. 1, pp. 3–13, 2010.

(14) J Laarni, N Ravaja, T Saari and T Hartmann, "Personality-related differences in subjective presence", In Proceedings of the seventh annual international workshop presence. Valencia: UPV, Valencia, 2004.

(15) A Caspi, BW Roberts and RL Shiner, "Personality development: Stability and change", Annu. Rev. Psychol, pp. 453–484, 2005, Doi:10.1146/annurev.psych.55.090902.141913

(16) SE Kober, C Neuper, "Personality and presence in virtual reality: Does their relationship depend on the used presence measure", Int. J. Human-Comput. Interaction, vol. 29, no. 1, pp. 13–25, 2013. https://doi.org/10.1080/10447318.2012.668131

(17) H. Han-Chung et al, "Influence of temperament and character on online gamer loyalty: Perspectives from personality and flow theories", Comput. Human Behav., vol. 70, pp. 398–406, 2017. https://doi.org/10.1016/j.chb.2017.01.009

(18) A. Sepúlveda, F. Castillo, C. Palma and M. Rodriguez-Fernandez, "Emotion recognition from ECG signals using wavelet scattering and machine learning", Appl. Sci. (Basel), vol. 11, no. 11, 2021. https://doi.org/10.3390/app11114945

(19) R. Castaldo, P. Melillo, U. Bracale, M. Caserta, M. Triassi and L. Pecchia, "Acute mental stress assessment via short term HRV analysis in healthy adults: A systematic review with meta-analysis", Biomed. Signal Process. Control, vol. 18, pp. 370–377, 2015. https://doi.org/10.1016/j.bspc.2015.02.012

(20) R. F. Navea, P. J. Buenvenida and C. D. Cruz, "Stress detection using galvanic skin response: An android application", J. Phys. Conf. Ser., vol. 1372, no. 1, 2019. doi: 10.1088/1742-6596/1372/1/012001

(21) C.-A., Wang, T. Baird, J. Huang, J. D. Coutinho, D. C. Brien and D. P. Munoz, "Arousal effects on pupil size, heart rate, and skin conductance in an emotional face task", Front. Neurol, vol. 9, p. 1029, 2018. https://doi.org/10.3389/fneur.2018.01029

(22) S. Grassini, K. Laumann, S. Thorp and V.M. Topranin, "Using electrophysiological measures to evaluate the sense of presence in immersive virtual environments: An event-related potential study", Brain Behav, vol. 11, no. 8, p. 2269, 2021. https://doi.org/10.1002/brb3.2269

(23) E. Baka, K. E. Stavroulia, N. Magnenat-Thalmann and A. Lanitis, "An EEG-based evaluation for comparing the sense of presence between virtual and physical environments", Proc. Comput. Graph. Int., 2018. https://doi.org/10.1145/3208159.3208179

(24) P. G. Malghan and M. K. Hota, "A review on ECG filtering techniques for rhythm analysis", Res. Biomed. Eng, vol. 36, no. 2, pp. 171–186, 2020.

doi: 10.25100/iyc.v27i2.14737

(25) M. Z. Zadeh, S. Niketeghad and R. Amirfattahi, "A PLL based adaptive power line interference filtering from ecg signals", in 16th CSI Int. Symp. Artif. Intell. Signal Process. (AISP 2012). pp. 490–496. DOI: 10.1109/AISP.2012.6313797.

(26) S. Mirza, K. Bhole and P. Singh, "Fetal ecg extraction and qrs detection using independent component analysis", in 2020 16th IEEE Int. Colloq. Signal Process. Its Appl. (CSPA). pp. 157–161. DOI: 10.1109/CSPA48992.2020.9068696.

(27) P. Kligfield et al, "Recommendations for the standardization and interpretation of the electrocardiogram: Part I: The electrocardiogram and its technology: A scientific statement from the American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; the American College of Cardiology Foundation; and the Heart Rhythm Society: Endorsed by the International Society for Computer", Circulation, vol. 115, no. 10, pp. 1306–1324, 2007. https://doi.org/10.1161/CIRCULATIONAHA.106.180200

(28) T. Baumgartner, D. Speck, D. Wettstein, O. Masnari, G. Beeli, and L. Jäncke, "Feeling present in arousing virtual reality worlds: Prefrontal brain regions differentially orchestrate presence experience in adults and children," Front. Hum. Neurosci, vol. 2, p. 8, 2008. https://doi.org/10.3389/neuro.09.008.2008

(29) G. Beeli, G. Casutt, T. Baumgartner, and L. Jäncke, "Modulating presence and impulsiveness by external stimulation of the brain", Behav. Brain Funct, vol. 4, no. 1, 2008.

(30) A. Perkis et al, "QUALINET white paper on definitions of immersive media experience (IMEx)," ArXiv (cs.MM), 2020.

(31) D. Archer and A. Steed, "Optimizing performance through stress and induction levels in virtual reality using autonomic responses," in 2022 IEEE Int. Symp. Mixed Augmented Reality Adjunct (ISMAR-Adjunct), 2022. doi: 10.1109/ISMAR-Adjunct57072.2022.00129

doi: 10.25100/iyc.v27i2.14737