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Metaverse and neuromarketing: methodological innovation in the study of the consumer and the retail

Metaverso y neuromarketing: innovación metodológica en el estudio del consumidor y del retail

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Abstract

Neurotechnologies lead to the study of the nervous system and the improvement of its function, and they are aimed to represent one of the great technological leaps of our time. Traditionally, they have been used in the field of health; however, their widespread adoption due to operational efficiency and cost has driven their use in various areas within the social sciences through the discipline known as neuromarketing or consumer neuroscience, applying it to market research.

The emergence of the metaverse could introduce new methods for studying individuals and audiences due to the wide range of neurophysiological recording sensors (eye tracking, EEG, EDA...) incorporated into virtual reality and augmented reality hardware. This paper focuses on the potential of these technologies in the context of the metaverse for researching consumers' interests in a broad range of business areas such as communication, fashion, advertising, tourism, and even education.

To depict this situation, a literature review, document analysis, and interviews with experts in cognitive neuroscience, artificial intelligence (AI), and neuroarchitecture are conducted. The research highlights the interest of consulting firms in using virtual reality for the design and analysis of retail environments and product placement. While the results demonstrate the presence of neurophysiological sensors in metaverse devices and the possibility of conducting neurophysiological research, there are still technological and basic scientific knowledge obstacles to overcome.

Keywords

Metaverse, neuromarketing, innovation, consumer behavior, artificial intelligence, TIC, business, retail, fashion, gaming.

Resumen

Las neurotecnologías conducen al estudio del sistema nervioso y a mejorar su función, y están llamadas a representar uno de los grandes saltos tecnológicos de nuestros días. Tradicionalmente han sido utilizadas en el campo de la salud, sin embargo, su universalización, por operatividad y coste, ha impulsado su empleo en diferentes áreas dentro de las ciencias sociales mediante la disciplina denominada neuromarketing o neurociencia del consumidor para aplicarla en la investigación de mercados.

La aparición de metaverso podría incorporar nuevas fórmulas para el estudio de individuos y audiencias debido a la amplia gama de sensores de registro neurofisiológico (*eye tracking*, EEG, EDA…) incorporados en el *hardware* de la realidad virtual y la realidad aumentada. El presente trabajo se focaliza en el potencial de las mencionadas tecnologías en el contexto de metaverso para la investigación de consumidores de interés en una amplitud de ámbitos empresariales como puede ser la comunicación, la moda, la publicidad, el turismo, o incluso la educación.

Con el objeto de retratar dicha situación se lleva a cabo una revisión bibliográfica, un análisis documental y entrevistas a expertos en neurociencia cognitiva, inteligencia artificial (IA) y neuroarquitectura. La investigación señala el interés de consultoras por el empleo de la realidad virtual en el diseño y análisis de entornos de *retail* y de emplazamiento de producto. Si bien los resultados evidencian la existencia de sensores neurofisiológicos en los dispositivos de metaverso y la posibilidad de realizar investigación neurofisiológica, todavía existen obstáculos tecnológicos y de conocimiento científico básico que superar.

Palabras clave

Metaverso, neuromarketing, innovación, comportamiento del consumidor, inteligencia artificial, business, retail, moda, gaming.

Introduction

The metaverse, a virtual environment in which individuals interact and experiment through avatars and digital entities, and it is transforming the way brands and commerce will relate to individuals. Virtual reality opens new spaces to understand the cognitive and emotional processing of the human being (Riva and Wiederhold, 2022) through neuroscience methodologies. There are many laboratories works that analyze brain activity through neurotechnology (Barrios *et al.,* 2017), which is called to become the great technological leap of our days (Aguiar, 2021).

Virtual reality (VR) environments drive methodological innovation, especially around techniques and metrics that enable biometric and physiological monitoring (Dincelli and Yayla, 2022; Egliston and Carter, 2021). Electrocardiography (ECG), electrooculography (EOG), respiratory rate (RR) or temperature (TMP), electrodermal activity (EDA), electroencephalography (EEG), electromyography (EMG) (Angelini *et al.,* 2022; Dincelli and Yayla, 2022; Guo and Gao, 2022) are susceptible to be introduced into VR research.

Metaverse offers an alternative reality through immersive and interactive virtual worlds that rest on VR (*virtual reality*), AR (*augmented reality*), and MR. (*mixed reality)* (Ning *et al.*, 2021). While its headsets and other peripheral devices integrate neurophysiological ledger sensors required to support VR/AR systems, this technology would have potential to be used in commercial research. This article reflects on the role of these technologies in the context of metaverse and consumer understanding.

2. Methodology

The research investigates the potential of neurophysiological technologies in the metaverse environment. Specifically, it will seek to:

1. Identify neuro implementable technologies in metaverse
2. Recognize the potential of neurophysiological technologies in the metaverse:
   2.1. Validity in the neurophysiological registry
   2.2 Cognitive and emotional processes
   2.3 Benefits for companies and users

3. Identify the protocols of commercial research in metaverse with neurophysiological technologies
   3.1 Protocol
   3.2 Professional profiles
4. Reveal the potential of this research in the company
5. Determine the factors that will normalize commercial research

A search was conducted in Scopus under the keyword "Metaverse" and filtered by discipline: psychology, medicine, decision sciences and neurosciences. From 1 January 1995 to 20 July 2022, a total of 68 publications were obtained. It was found that there are no articles that address, from the business approach and commercial research, the potential of neurophysiological techniques in the metaverse, VR/AR. In addition, the *websites* of 21 neurotechnological startups listed by CBInsights (2019) and the 52 members of companies of the Neuromarketing Science & Business Association (NMSBA) were analyzed.

In addition, seven experts in cognitive neuroscience, computational science, artificial intelligence and neuroarchitecture are interviewed, most of them with research in VR and the use of neurophysiological technology. The semi-structured questionnaire is designed on the basis of previous research by the authors on metaverse and neuroscience (Crespo-Pereira *et al.,* 2023), and the questions emanate directly from the objectives described. Interviews were conducted online in the fourth quarter of 2022. One was replied to by email. Once concluded the round of interviews the responses have been anonymized and presented randomized in Table 1.

The study addresses the five quality parameters of Miles *et al.* (2013): objectivity/confirmability (a system of categories and codes is established and MAXQDA is used); reliability/confidence (foreign studies are considered for theoretical dialog and the final manuscript is shared with experts for its review), credibility/authenticity (triangulation of methods—interviews, documentary analysis and bibliographic review—unify, clarify and solidify the results), transferability/adequacy (conclusions are commercially applicable in multiple fields), utilization/application (a potential phenomenon involving present and future business activity is analyzed).

Table 1
Experts

Name	Affiliation and field of knowledge
Senén Barro	Director of the CITIUS-Unique Center for Research in Intelligent Technologies of the University of Santiago de Compostela Artificial intelligence
Juan Jesús Torre Tresols	ISAE-SUPAERO Neuroscience, BCI, artificial intelligence
Juan Luis Higuera Trujillo	Polytechnic University of Valencia Architecture; specialization in neuroarchitecture
Dulce Milagros Rivero	Pontifical Catholic University of Ecuador-Sede Ibarra Artificial intelligence
Rob Cecilio	CEO Dendron Neurotechnologies Computational neuroscience
Irene Alice Chicchi Giglioli	Polytechnic University of Valencia Clinical psychologist
David Glowacki	CITIUS researcher Virtual reality and computer science

Results

First Perspective: Neurophysiological Technology in Metaverse Devices

The most advanced technological state aims at the communication of the mind with the machine by using the brain-computer interface (BCI) thanks to the EEG (Ning *et al*., 2021; Park and Kim, 2022). EEG, the classic neuroscience technology (Ning *et al*., 2021; Park and Kim, 2022) and the most used in the development of BCI (Barrios *et al.,* 2017; SSVAR, 2022), employs scalp-based sensors for the recording of neural activity (Cinel *et al*., 2019) and facilitates the encoding and decoding of brain signals and sending orders to devices.

The BCI-EEG is used today in VR environments to know the functioning of the brain and create therapies to restore mobility and sensations in patients with severe disabilities (Lebedev and Nicolelis, 2017), in addition to its ability to allow simulations and experiments on cognitive processes in a controlled laboratory context (Cannard *et al*., 2020) and attractive to motivate the subject (Barrios *et al.,* 2017).

The existence of portable, inexpensive and non-invasive neurophysiological technologies could drive commercial applications (SSVAR, 2022; Lee and Kim, 2022; Park and Kim, 2022; Rauschnabel *et al.,* 2022; Riar *et al.*, 2022) (Table 2). Non-invasive BCIs open the door to their mass consumption in the metaverse field, beyond the sanitary application (SSVAR, 2022). Some authors consider that the BCI is called to form the third foundation in the construction of the metaverse (Brambilla-Hall and Baier-Lentz, 2022).

The technology (BCI-EEG) can be used together with *the head mounted displays* (HMD) of VR/AR/MR. in various educational and leisure activities: video games (Idun Technologies, n.d.), entertainment and communication (Ienca and Andorno, 2021). Pioneering initiatives show their interest in the mass market. Meta (formerly Facebook) proposed creating, in collaboration with UCSF, a non-invasive BCI helmet to redefine the AR/VR experience (Makin *et al.,* 2020; Tech at Meta, 2020). For Meta, the future of metaverse is found in the sciences of perception and AI and mixed reality with haptic devices, hand tracking and eye-tracking (CNET Highlights, 2022). Other technologies have developed gloves, bracelets and bodysuits to enhance the user's sense of touch and emotions (Park and Kim, 2022; Tayal *et al*., 2022).

Gesture and voice recognition, thermal and haptic detection systems will facilitate the feedback needed to provide higher levels of immersion in virtual environments (Shepard, 2022). With thermal haptics, users will be able to feel the temperature of a virtual object and have a more realistic interaction with their environment; while with ultrasound-based haptics, pulses produced by special speakers will create skin-sensitive pressure points. It will be applied in video games, vending machines*,* shopping kiosks… (Shepard, 2022).

Eye *tracking*, an eye tracking technology that records, among others, movement and attention patterns, is incorporated into headsets (Egliston and Carter, 2021b) and facilitates optimization in experience design (Rogers, 2019).

Metaverse virtualizes and dates the movements of the individual to translate physical experiences into virtual ones (AEDP, 2022). The Internet of things and neural interfaces act as a bridge for physical-virtual interaction (AEPD, 2022). Technologies to enrich sensory experiences (auditory, haptic, visual, olfactory…) (Egliston and Carter, 2021b) provide neurophysiological information of potential interest for commercial research.

Table 2
Metaverse devices and neurophysiological recording sensors

Technology	Built-in sensors
HP Reverb G2 Omnicept Company: HP	It includes a system of *eye tracking* sensors, *face tracking* and *heart rate* in the HMD.
Spectacles Company: Snap	AR glasses. NextMind, a developer of BCI-EEG and *eye tracking*, belongs to Snap.
Oculus Quest 2 Company: Meta	It has body motion recording sensors, an accelerometer and a gyroscope. Meta works on a wrist interface, an electromyography (EMG) bracelet, to detect motor neurons that signal the intended movement of the fingers.
AR glasses Company: Google	They include facial recognition.
Magic Leap 2 Company: Magic Leap Inc.	AR glasses with *eye tracking* cameras. Professional and industrial orientation.
PSVR Company: Play Station	VR glasses have sensors for movement and *eye tracking*.
Hololens Company: Microsoft	MRI technology that uses holograms. Introduces accelerometers, gyroscopes, *eye tracking* and *voice tracking*. Educational and health use.
Galea Company: OpenBCI	MR. BCI-EEG helmet. Integrates EMG, EEG, EOG, EDA, PPG, ET into one device.
Vive Flow Company: HTC	They incorporate *eye tracking* (Tobii). Consumer and professional market. Designed for entertainment, *gaming*, metaverse, sales/ marketing, *training*, learning.
Valve Index Company: Valve	It has an accelerometer, gyroscope and motion sensor for a more realistic effect of interaction with the virtual world. Designed for VR games.
Samsung Gear VR Company: Samsung	Goggles for video games and audiovisual content. It has *eye tracking*, *hand tracking* and facial recognition.
Apple Glass Company: Apple	VR glasses. They are expected to incorporate 14 cameras, some to detect facial expressions that allow their representation in an avatar.
Canon MREAL X1 Company: Canon	Augmented reality glasses. It has *hand tracking*. Professional/ business use.

Note. Own elaboration from Angelini *et al*. (2022), HP (2022), CNET (2022b), Spectacles (2022), Marquez (2022), Spectacles (2022), Bezmalinovic (2022), Leswing (2022), Magic Leap (2022), Abraham (2021), Hololens (2022), Bitnamic (n.d.), Schneider (2022), Brown (n.d.), Galea (202 2), López (2022), HTC (2022), Valve (n.d.), Carter (2022), Muñoz (2015), Miller (2017).

Perspective 2: Neurophysiological recording technology and commercial research

Research possibilities in VR/AR environments

VR/AR *hardwares* with integrated neurophysiological sensors may be in regular use in the future. Currently there is evidence of its implementation, at least in an operational manner (Table 3). These sensors open a methodological way around techniques and metrics that eliminate the biases of techniques that depend on verbalized response (Dincelli and Yayla, 2022). Opinion shared by the interviewees (E1, E3).

Experts point to a wide range of technologies in the field of neuroscience and psychology in the study of the subject. The possibility of incorporating a wide variety of sensors to helmets and VR devices (EEG, ECG, EDA…) (E1, E2, E7) is indicated. In addition, there are a large number of *wearables* in the consumer market (e.g. smart watches…) that record physiological data and identify mood; these could be combined during the use of metaverse for studying the subject (E1).

Research with neurophysiological sensors is possible in the laboratory, but its application in real scenarios of use must overcome certain obstacles (E1, E2, E3, E4, E6, E7).

- There is great variability in the reliability of the sensors incorporated in existing devices (E2, E7), however, HTC Vive helmets are used in laboratories because of the quality of their sensors (E5).
- The devices weigh a lot and may cause a headache (E4).
- Better sensors needed – reliable, cheap – (E2)
- Appliances must be properly placed (E2, E3, E7)
- Progress is needed in AI (E2) and *machine learning* (E7), as well as in signal filtering that ensures the business usefulness of data (E2, E2, E7).

Table 3
Neurophysiological recording technologies applied in VR/AR devices

Technology	Registration
Accelerometers	It records body movement (arms, hands, fingers) as well as postures using sensors. It is implemented in *wearables* like *smartwatches* to offer information search, entertainment or *healthcare* services. A pioneering example is Microsoft's Kinect, which employed motion interfaces, new forms of interaction in virtual worlds.
Electrocardiogram (ECG)	The electrocardiogram records the electrical activity of the heart, heart rate (HR), heart rate variability (HRV).
Electrodermal activity (EDA)	This technique measures electrical conductivity mainly through sweating of the skin. It is useful for measuring emotional reactions and stress.
Electromyography (EMG)	Electromyography measures muscle contraction. Another derivative technique is facial EMG, which records the movements of facial muscles in order to determine emotional states.
Electroencephalogram (EEG)	It records neural electrical activity. It is used for CCBs.
Eye tracking (ET)	It records the gaze, fixations, saccadic movements, pupil dilation, blinking rate. It is used to analyze cognitive processing (attention), used in marketing studies, usability and *human-computer interaction*.
Breathing (RESP)	It records respiratory activity, respiratory rhythm.

Note. Own elaboration from Dionisio *et al*. (2013), Angelini *et al*. (2022), Halbig and Latoschik (2021), Gakhal and Senior (2008), Ohme *et al*. (2011)

In addition, not all sensors provide deep information on emotional and cognitive processes; for this reason, EEG should be incorporated, thus making research extraordinarily complex (E2, E3, E7). The idea that this technology can "read the mind" is a fallacy (E2). Today, research in real environments using VR with EEG poses methodological problems to be overcome (E7):

- Variability in reliability and validity in the off-laboratory data recording (E2, E3, E7).
- Data recording in noise, motion… (E2, E3, E7) and filtering of strange variables (E2, E7).
- Reliability of commercial EEGs (E2, E7).
- Connectivity of non-invasive EEGs without gels (E2).
- The quality of the electrodes circumscribed to the frontal areas and the usefulness of this information (E2, E7).

- BIC-EEG ergonomics with AR/VR (E3) devices.
- The complexity of handling EEGs (E2, E7) and their proper placement (E2, E3, E7).

Emotional and cognitive recording

The Academy has reported a high volume of work that employs physiological metrics in VR environments to understand the cognitive and emotional processing of the human being before certain stimuli (Venkatesan *et al.,* 2021). Studies on neurophysiological and VR technologies focus on the creation of methodologies and systems for recognizing evoked emotions (Marín-Morales *et al.,* 2018). Research on affective/emotional states in immersive virtual environments with physiological data is relatively new and growing (Marín-Morales *et al.,* 2018; Dozio *et al.*, 2022). This is highly relevant as emotions affect behavior (Mandolfo *et al.*, 2022). Virtual reality environments simulate real-world scenarios and offer various sensory inputs measurable with neurotechnology (Parsons and Duffield, 2020). The virtual worlds thus become spaces of interest for companies linked to retail, fashion, media, education or tourism.

There is a wide range of technologies applied in the study of emotion in the context of virtual reality: EEG (in the form of a *headset* or as a textile electrode), pupilometry, EDA… (Halbig and Latoschik, 2021; Marín-Morales *et al.,* 2018). Traditionally, the emotional states before stimuli have been measured according to a two-dimensional system formed by valence and *arousal*. While valence demonstrates the degree to which a response is positive or negative, *arousal* measures the degree of activation associated with an emotion (Bolls *et al.*, 2001).

Real-time psychophysiological data recording provides information regarding cognitive states (Marín-Morales *et al.,* 2018). Classical approaches in VR experience assessment tend to employ physiological measurement devices to monitor attention, stress, meditative state (Orlosky *et al*., 2021), anxiety, cognitive load (Halbig and Latoschik, 2021). These are applicable in: therapy, training and simulation (Angelini *et al.*, 2022), learning, entertainment and communication (Halbig and Latoschik, 2021).

Several technologies, such as *chest bands* and bracelets have been used to record stress, providing relevant data on skin conductance and cardiovascular information. Body temperature, breathing, movement, and ECG are also part of this type of study. Cognitive load indicates how demanding a task can be and, therefore, the mental effort invested in an activity.

This is particularly interesting in the field of simulation and learning in VR environments. Studies with EEG and EDA monitor various levels of cognitive load. The *wearable* bracelets also provide interesting cardiovascular information to assess load levels. EEGs are the most used to assess this aspect. Other studies also show the effectiveness of *eye tracking* and eye measurement, being especially relevant given its implementation in HDM (table 3). Anxiety can be monitored with sensors for cardiac variability, body temperature, skin conductance, and EEG (Halbig and Latoschik, 2021).

Using physiological data in the context of VR would facilitate research such as (Halbig and Latoschik, 2021):

- Comparison of physiological responses in virtual versus real scenarios.
- Comparison of groups by differences in physiological reaction.
- Process analysis by monitoring physiological changes in virtual simulations.
- Analysis of progress through the identification of changes in response to the same stimulus in multiple exposures.
- Correlations and establishment of relationships between the measurement of variables.
- User rankings based on responses/segmentation.
- Visibility of unconscious and latent processes.
- Adaptation of the contents to the user according to indicators of effort and stress.

Applications and benefits of neurotechnology for the company

The functional benefits of neurophysiological technology (B.F) for metaverse support and those derived from user research (B.I.) with neurophysiological techniques are listed below (Table 4).

Table 4
Benefits of Neurophysiological Technology

	B.F.	B.I.	Source
Physiological sensors in commercial *headsets* will enrich emotional interactions	x		(Angelini *et al*., 2022)
Eye tracking and facial recognition add verbal and non-verbal cues in the creation of digital avatars that better represent emotional states	X		(Halbig and Latoschik, 2021) (Angelini *et al*., 2022)
Eye tracking as a subject identification system. Recognition of preferences and customization of environments	X		(Rogers, 2019)
Identifies user presence	X		(Halbig and Latoschik, 2021)
These technologies enable user-friendly designs that enhance experiences		X	(HP, 2022) (Halbig and Latoschik, 2021) (Rogers, 2019)
Identification of attentional and distracting patterns through *eye tracking*		X	(Halbig and Latoschik, 2021) (Rogers, 2019)
Assessment of the effectiveness of the scenarios and their emotional impact (therapies…)		X	(Halbig and Latoschik, 2021)
The emotional *feedback* can revert in the self-regulation/feedback of contents and derives from the game for its efficiency in relation to training and well-being		X	(Angelini *et al*., 2022) (HP, 2022) (Halbig and Latoschik, 2021) (Rogers, 2019)

Eye tracking systems or absolute positioning in real environments can be employed for a host of applications, including those related to marketing or consumption (E6). These technologies allow users to identify and create profiles of users with behavioral patterns (E1, E6), which would facilitate personalized recommendations (E1, E2, E3). The tandem they would form with AI and machine learning would ensure behavioral prediction thanks to the high volume of data potentially collected with the sensors (E1, E2, E5, E6).

On the other hand, the suggested methodology could become relevant in the design of contents/*inputs* and the optimization of the mood by quantifying the emotional effects before stimuli shown in immersive virtual environments (Marín-Morales *et al.,* 2018). In the metaverse, the identification of emotions is crucial for avatars to emulate human beings, since they must learn to express emotions (E1). Thanks to the physiological record, users will be able to know what excites, stresses, calms … and stimulates in one way or another (E1). Other potential benefits:

- Reliability and objectivity of investigations (E3).
- Identification of the most effective (liked and disliked) and attractive content (E1, E2, E3, E4) for any field – education, media, advertising – (E1).
- Content customization/advertising/educational (E1, E2, E3, E4).
- Design of various environments such as educational (E7) as well as *retail* and product placement (E1, E5).
- Secure access to platforms through biometric identification (E2).

State of the art on commercial studies

Neurotechnologies develop innovative technologies in the field of neuroscience. The companies analyzed allocate these resources in VR environments to relieve chronic pain, cognitive rehabilitation, and motor. Few evidence their relationship with *gaming* and/or commercial research (Kernel, Brain CO., Emotiv, Neurable, BitBrain technologies, NextMind, MindMaze); and fewer that are applied in VR contexts (table 5).

Table 5
Neurotechnology and its business relationship

Company	Description and application
Kernel	It develops neuroimaging (EEG) technology and it is applied in VR studios in areas such as *gaming,* entertainment, and consumer products.
Dreem	Neurotechnology to monitor brain activity during sleep.
Thync	Development of a neurostimulator to combat stress, anxiety, tension and improve sleep.
Halo neuroscience	Development of technology for neurostimulation and mental health. Company purchased by Flow Neuroscience.
Synchron	It develops invasive BCI, Stentrode to be used by patients with paralysis.
Brain Co., Inc.	It has a *wearable* BCI and *headbands* for education, fitness and video games.
Neurable	It develops BCI. It targets the AR/VR gaming industry. In 2017 it introduced the first mind-controlled virtual reality (VR) game.

Company	Description and application
Neuralink	It develops invasive BCI.
Flow neuroscience	It develops an earpiece that provides transcranial direct current stimulation on the forehead to treat depression.
Cognixion	It works with BCI, AI and AR for people with communication difficulties.
Bitbrain technologies	Spanish company that creates neurotechnology and offers consultancy (neuromarketing).
Paradromics	It creates invasive BCI technology for people with communication difficulties.
Meltin MMI	A Japanese company that develops cyber augmentation technologies, including a "cyborg" hand called MELTANT-α. It works in the processing of biosignals.
Neuros Medical	Biomodulation company focused mainly on pain relief.
NextMind	It develops BCI and targets the consumer market.
Emotiv	It creates hardware and software for medical and business use.
Q30 Innovations	Aimed at athletes and military personnel; its main product is the Q-Collar, a wearable device designed to protect the brain.
BIOS	Company of neural interfaces destined to control prosthesis.
Neuroscouting	Sports technology focused on analyzing the performance of athletes and trying to predict their potential.
NeuroPace	It develops medical technologies to reduce epileptic seizures.
MindMaze	It employs gamification and VR to help with neurorehabilitation.

Of the 52 members of the NMSBA, only two allude to the use of neurophysiological sensors in VR. Tobii performs attention studies (ET) in VR scenarios that allow:

- Avoid the use of highly complex physical scenarios.
- Reach a high sample.
- Control digital spaces and adjust to *packaging* and store design requirements without the need for their physical version.
- Analyze digital images.

Tobii (n.d., n.d.b) wants technology to be useful for creating realistic avatars and intuitive interfaces and as a tool for authentication. It sees social apps and games as the areas where consumers will appreciate the metaverse the most. Neurons (n.d), on the other hand, is analyzed through an EEG *headset*, a VR conversation *versus* in-person conversations. Similar levels of emotional *engagement* were demonstrated in both cases. VR has been hailed as the next big thing.

Benefits for the user

Interviewees point to the value of VR and neurophysiological sensors for research in laboratories and for health/education/social purposes. Virtual environments would enable user diagnosis and rehabilitation (E2, E3, E4, E5). EEG in a VR scenario is used today to detect anxiety and potentially depression (E2, E3). Virtual reality could propose stimulating content and designs for the well-being of the user (E3, E7) and boost the feeling of social connection highly beneficial for the subjects (E4). AI would simplify users' lives by providing data on health status and information relevant to decision-making (E1).

Investigation Protocol

Currently, subjects share personal and behavioral data through their mobile, social networks and *wearables* (E1, E4, E7). The human body becomes a technological platform; the internet of things is now moving to the internet of bodies, full of sensors to collect data in real time (E1).

The recording of data with neurophysiological sensors would not differ from the current Meta model or similar ones (E1). Metaverse is designed to collect data, and the inclusion of neurophysiological information could enrich this "data emporium" (E1). Metaverse could become an ideal platform for research outside the laboratory due to its high volume of volunteer participants in realistic and unpaid environments (E1, E3).

The existence of *hardware* with integrated sensors and *software* is a necessary condition for research in real environments. At login, the platform could register various metrics of commercial advantage (E1). Neurophysiological information is at the highest level of legal protection (E2). The express consent of the user, prior registration of data by third parties is mandatory (E1, E2, E3, E4, E5, E6). While European legislation is highly warranted, US legislation could be looser in coverage (E2). It is remarkable how easily users authorize the sharing of their data to access *online* content (E1, E4).

The consent will depend on the interest aroused by the content (E3) and the ownership will always be of the individual (E2, E4); however, once the developer of the platform anonymizes the data and treats them collectively, they will be their property (E1; E2; E3). The way this data is used will be relevant. Its purposes must be the right ones (E1).

It should be clarified that collecting data in a real-world scenario is a complex task (E2, E3, E4, E5, E7). The collection itself could present insurmountable obstacles at present (see 3.2.1.); to this is added a basic methodological question, the design of the investigation (E2, E3, E7), which must attend to each particular case (E7). The objective (E2, E3, E6, E7) and the appropriate techniques for that purpose (E2, E3, E7) should be defined. It is necessary to specify the actions to be analyzed and select some markers that are perfectly synchronized and identified and facilitate the collection of data, whatever they are (e.g. the look) (E2, E3). These markers should be consulted and agreed with experienced experts to identify stakeholders who are interested in analyzing and providing valuable information and thus help to draw valid conclusions (E3). When the data is collected, it must be cleaned and labeled (*data labelers*) to create a database to work with from the AI (E1, E3). Thanks to this process it will be possible to identify cross-sections of the entire sample in the same situation (E2, E3) and establish behavior dynamics (E1, E3). The categorization of subjects into patterns will facilitate decisions on content management, informed and linked to the possibilities offered by AI (recommendations, customization …) (E1).

It is unquestionable that research should adhere to scientific protocol. Data interpretation should be rigorous (E2, E3, E7), thus, we should not fall into reductionism (E2). Today, the challenge for the scientific community is to obtain, through this type of records, clear indications about what happens, so that the exit from the laboratory is, at least, complex (E2, E3, E7). However, it is pointed out that research with video games is highly appropriate, because it is framed in controlled scenarios and has hard rules that limit actions and action spaces (E3). If a platform wants to conduct research in its digital gaming environments it will be able to implement challenges, levels and activities (E3). Suggested research might be a bit easier for developers with their own *hardware* and *software*, as the independent researcher should separately process consent from users and from *hardware* and *software* developers (E3).

Professional profiles

The professional team formed for commercial research should be the same as the one created for an academic research (E7). Teams outside the scientific/academic community may not adhere to the scientific protocol (E7). Although the team should not be formed without first identifying the problem to be solved (E4, E6, E7), the following profiles potentially involved in an investigation such as the proposal are suggested:

- Specialists in cognitive neuroergonomics, physiological ergonomics (E3).
- Robotics experts (E6).
- Engineers able to write code; *software* engineers (E4).
- Graphic artists to design VR environments (E4).
- Expert in cognitive modeling (E2).
- Experts in extended reality (E6).
- Experts in *big data* (E6), mathematicians, statisticians (E1, E2), *data scientist* (E1, E2).
- Experts in AI, *machine learning* (E1, E5, E6, E2), *data labellers* (E3).
- Computer vision experts (E6).
- Expert in physics for signal processing (E2).
- Biomedical engineers for handling sensors (E4).
- Neuroscientists or biomedical engineers for data interpretation (E1, E2, E4).
- Expert in Cognitive Sciences (E2) and Computer Science (E2).
- Psychologists or *coaches* expert in leading group processes (E4, E2).
- Experts in the area of research interest: Marketing, Communication, Education, Fashion… (E1, E2, E4, E5).

Future of commercial research

Just as social networks evolved under the cover of new commercial applications, metaverse could experience a similar situation. The company must identify the potential of these tools and create products tailored to their needs (E1). Once the product is launched, *software* developers will create products and AI will demonstrate its capabilities (E1), but first metaverse must become a reality (E1, E2, E3, E4, E5). Its normalization depends on the cost and democratization of VR glasses, among others (E1, E2, E7).

Neurophysiological investigation in the metaverse under conditions of real use is theoretically possible. Some do not doubt its future commercial interest (E1, E6, E7), although much remains to be done (E2, E3, E7). VR/AR/MR. has improved exponentially in recent years, both the *hardware* (more economical, powerful, sensorized, robust…), as well as the algorithms and *software* available – even free to use – (E6). However, the leap from laboratory to home will require a major technological and scientific leap (E2, E3, E7) (see 3.2.1.). There is a gap between the expectations created and the results achieved today, caused by the claims of certain circles, media and the exercise of neuromarketing (E7).

Interest in this methodology will depend on the success of metaverse (E1), the recognition of its potential (E1) and its ability to generate business/social/educational benefits (E1, E3). This requires leading and innovative companies that lead the way and then join others: SMEs and research groups (E3, E6). Big tech companies like Meta and Google have resources, but not all of their proposals are successful (E3, E4). Interest in virtual worlds is not new. We would be looking at the third attempt to promote experiences linked to VR/metaverse (E4). The user will not be interested in them as long as they have everything they need on their smartphone (E4) and do not offer experiences other than reality (E4), because the physical experience will never exceed the virtual one (E5). In spite of the million-dollar investment in metaverse, it seems that the projects of Meta and other technological projects (E3, E4, E5, E7) do not take off. The stock market value of technology companies at the end of 2022, shows, at least, an uncertain future (E4, E5, E7).

Conclusions

Big tech companies have integrated non-invasive neurophysiological sensors (*eye tracking*, EEG…) into VR/AR *headsets* and peripherals. Although this technology is necessary to support VR/AR systems, the *feedback* it provides would have the potential to know the emotional and cognitive states of the user without the biases of verbal responses and in real-world environments of use. These technologies could lead to high-interest metrics in multiple fields (such as education, business…) and that provide large-scale benefits. At the moment, science and technology is not ready to deliver reliable results in non-laboratory settings. However, their business interest is evident. AI will become highly relevant in the exploitation of data, including for those arising from the neurophysiological registry, and in the creation of recommendation and personalization systems. Ethics and privacy become one of the great challenges of this type of metaverse research. Future approaches should include the perspective of the company and consultancies specialized in metaverse.

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