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Physiological assessment of User eXperience supported by Immersive Environments: First input from a literature review

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Abstract

Immersive virtual environments can support the co-design process during the early innovation stages. For these technologies to be used as a support tool researchers and designers need to better understand users' behaviors and experiences in these environments. While most of the existing literature proposes to assess immersive experiences using self-reported assessments such as questionnaires, some alternatives propose the use of physiological data. In this sense, biometric and physiological measures can be useful indicators to study human behavior and performance in immersive virtual environments in order to highlight what physiological data monitoring can bring to the understanding of user experience. Based on an analysis of 1850 papers retrieved from the main bibliographical databases, our paper is aiming to propose a systematic review of the scientific literature interested in the use of biometric evaluation of human behavior interaction in an immersive environment. Through this review, the different uses of the technologies and their perspectives as tools for the assessment of user experience in immersive environments are presented and discussed.

1. Introduction

Immersive or virtual environments can play an important role as tools to support the design and development of innovation projects. They have been used in multiple disciplines such as health (Vogt et al., 2015), entertainment (Parker et al., 2011), psychology (Wood et al., 2007), human behavior (Slater et al., 2006) and user experience (Silva et al., 2009). This shows a high potential for the technology as a tool in diverse applications. However, research on co-creation process involving user experience supported by immersive environment still needs more development (Dupont et al., 2018). Indeed, if the Immersive Collaborative Environment (ICE) tree describes the properties of collaborative experience and immersive experience (Dupont et al., 2017), we need to better understand how users interact with those technologies. Research methods in human-computer interaction have been developed to analyze user behavior and other human factors (Rubio-Tamayo et al., 2017). While most of the reported methods use self-assessment measures (i.e. questionnaires and survey), another part is based on the use of physiological measures (Rubio-Tamayo et al., 2017). However, the literature shows that these technologies have been used in many different ways to study immersive environment experiences and there is a plethora of methods and approaches. For this reason, it is important to make a synthesis on how biometric and physiological assessment have been applied to study immersive virtual environment experience for researchers to better use this approach. The aim of this study is therefore to propose a systematic literature review of Biometric assessment (or physiological assessment) in Immersive Environments (or virtual environment).

In this review, 1850 research articles published between 2000 and 2020 extracted from Scopus database were analyzed using a co-occurrence approach conducted with VOSviewer software. Next, from those articles 153

significant references in terms of biometric devices uses for assessment were selected and sorted. After this, 26 publications were analyzed to determine which parameters have been studied to evaluate virtual immersion. Finally, we summarized the biometric devices technologies found in the literature in three groups: Common Technologies, Original biometrics technologies and Non-typical biometric technologies.

The principal contribution of this work is to summarize relevant aspects of Biometric assessment in Immersive Environments: Which factors have been studied and which technologies have been employed.

The rest of this paper is structured as follows. In section 2, previous works on Immersive Virtual Environment (IVE) and a general background about the Biometrics devices used to measure IVE is developed. In section 3, Material and Methods are described. Sections 3 and 4 synthesizes the results and conclusions.

2. Previous works and general background

2.1. Immersive virtual environment experience assessment

While there are several tools (questionnaires) and models to study user experience on immersive environments (Tcha-Tokey et al., 2016), to our knowledge there are no other frameworks to analyze co-creation in virtual environments. For this reason, in this research we use the Immersive Collaborative Environments (ICE) tree structure developed by (Pallot et al., 2017). This model identifies the most relevant elements to assess immersive co-creation in virtual environments. These elements have been summarized in the Immersive Collaborative Environments (ICE) tree structure (cf. Figure 1).

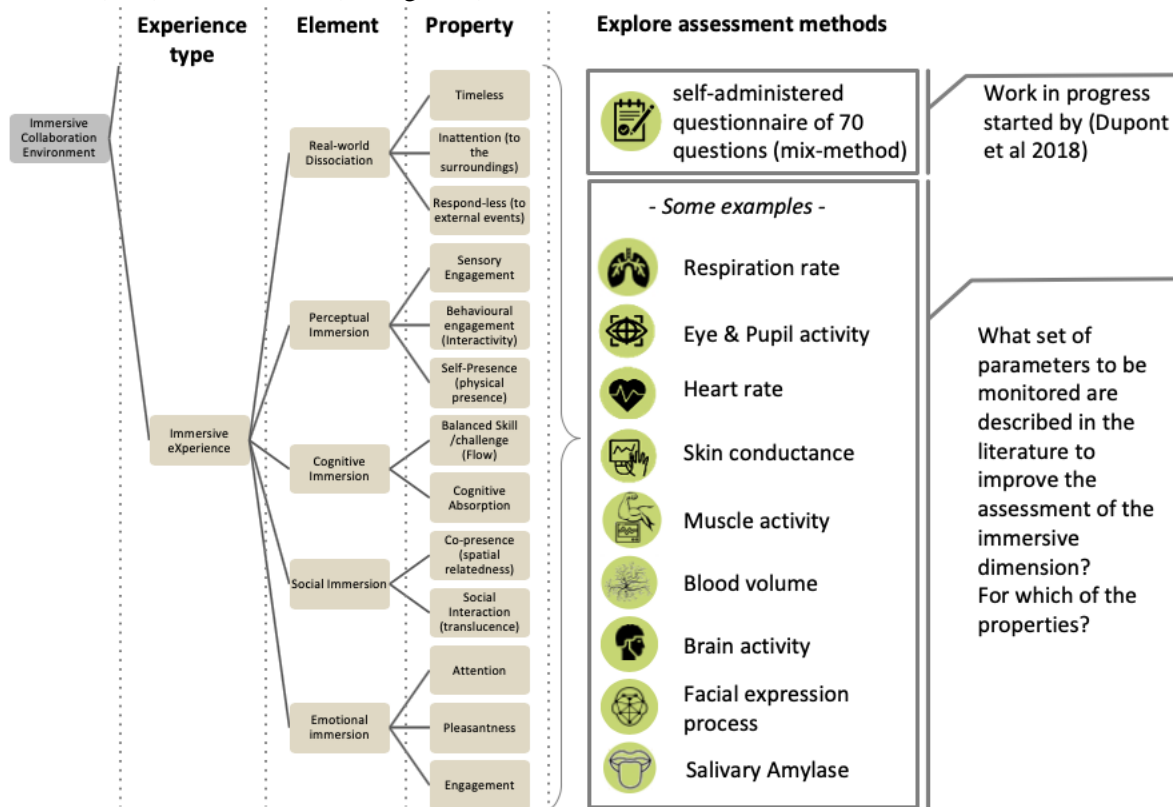


Figure 1. Exploration of assessment of immersive properties of the ICE structure based on (Dupont et al., 2017)

The ICE structure includes cognitive, social, perceptual and emotional facets. It is divided in two experience types: Immersive Experience and Collaborative Experience, both include their own elements and properties. The ICE tree has been applied by means of a questionnaire (self-reported measure) and survey instrument to assess the participants experience in immersive environments (Dupont et al., 2017). While the use of the ICE tree structure and the questionnaire instruments seems to give a complete picture of all the factors affecting the participants experience in immersive environments, self-assessment measurements present some limits because they rely on the ability and willingness of the respondent to accurately report their attitudes and prior behaviors (Lee et al., 2007). First experiments show the questionnaire is long and tedious for users. The participants are questioned

after the experience. How could we collect their feedback at the time of the action, or even automate part of the collection? There seems to be some part of the answer in physiological responses as they can be collected when respondents are directly participating in the behavior and are difficult to control. For this reason, in this research we are interested to study how some of the ICE tree structure properties can be observed by means of biometrical devices as an alternative (or complement) to the existing instruments. For example, can respiration rate or eye pupil activity be used to assess one or several of the model properties. Figure 1 presents the tree structure and some of the possible devices to be explored. Furthermore, as the collaborative and immersive dimensions are complex and attached to different fields of research in this initial literature review, we will focus solely on the Immersive dimension (Figure 1). The collaborative dimension will be explored in further research.

2.2. Physiological devices for experience assessment

As seen from the ICE tree the immersive experience is affected by cognitive, social, perceptual and emotional facets. There has been extensive research in the fields of human behavior and decision-making processes. This research has shown that emotion plays a critical role guiding decision-making and behaviors in response to stimuli (Damasio, 1994), and also plays a crucial role regulating the interactions between humans and their environment (Dalgleish, & Power, 2013; Eimer, Holmes, & McGlone, 2003; Naqvi, Shiv, & Bechara, 2006). The processing of emotions is predominant in the limbic system (Shalev et al., 2017) located in the brain's medial temporal lobe. This system is responsible for processing emotional stimuli and regulating the expression of emotional responses to integrate them into complex brain functions. This process integrates the Central Nervous System (CNS) and the dynamics of the Autonomic Nervous System (ANS) (Marín-Morales et al., 2019). Because of this, emotion has a great impact on body responses. This is the working principle exploited by many of existing biometric devices that relies physiological responses to assess emotional and cognitive impact, states or types.

One of the impacts of emotion in body responses is expressed through facial expressions: helped by some neuronal groups called Central Pattern Generator (CPG), it initiates and controls facial muscle activities (López Mejía et al., 2009). Thus, some emotions can be recognized by the means of facial expressions (Winkielman et al., 2008). In terms of user experience this measure is related with social interaction and intention of participants, willingness to interact (Sacco & Hugenberg, 2012), empathy (Lundqvist & Öhman, 2005; Ruggiero et al., 2017), and as a confidence or trust indicator (Van IJzendoorn & Bakermans-Kranenburg, 2012; Weber & Brewer, 2006). There are other patterns of physiological activation present in emotional states, such as: heart rate, respiratory rate, brain activity or galvanic activation of the skin (Hagemann et al., 2003). These can be used to measure the impact or relevance of a certain stimulus. However, it is difficult to identify with these biometric data alone to which of the six basic emotions the activation corresponds (Dawson et al., 2007). For this reason, it is often necessary to combine several of these measures (e.g. skin response and facial expressions).

Human emotional processing, interpretation of the facial expression process (Wicker et al., 2003), empathy (Jackson et al., 2005) and perception all involve the activity of the cerebral cortex and the CNS to automatically classify emotions and monitor the attentional meaning of emotions. Because of this, electroencephalogram (EEG) and fMRI are the most commonly used techniques to measure CNS responses (Valenza et al., 2016). In addition, EEG has been used to measure engagement (Castellar, E Voigt A., Jan N. & Marinazzo, D. & Looy, 2016; Cirett Galán & Beal, 2012; Shestyuk et al., 2019) and it can detect the perceived cognitive absorption (Conrad & Bliemel, 2016; Léger et al., 2014).

Changes on cardiovascular dynamics by specific emotional states (Marín-Morales et al., 2019) can be measured using electrocardiogram devices (ECG). Heart rate variability (HRV) has been used as an indicator of presence and pleasantness (Greenfeld et al., 2019; Jonathan et al., 2013; Meehan et al., 2002; Wood et al., 2007).

As a person becomes more or less stressed, the conductance of the skin increases or decreases proportionally (Slater et al., 2006). Galvanic Skin Response (GSR), is commonly used to establish the user's emotional states and it is used to measure sensory stimuli (e.g., pain, pressure, touch). In virtual reality settings it has been used as a presence indicator (Slater et al., 2006).

Finally, eye monitoring data, such as pupil dilation, fixations and saccadic eye movements, can determine pleasant or unpleasant emotions or reactions. Eye movement is measured by the mean of eye tracking devices.

The provision of information on the position of the eye is also related with a measure of joint-presence between two people (Špakov et al., 2019), attention (Wang et al., 2015), and it has been used as an indicator of context awareness (Bulling et al., 2008).

As seen from this brief literature background, some of the properties included in the ICE tree for immersive experience assessment have been assessed with the use of physiological measures. In particular presence attention, engagement and pleasantness. However, we need to better understand how authors have assessed those particular properties with physiological devices and if the other properties have been assessed. For this reason, we performed a systematic literature review on the use of physiological devices for the assessment of immersive environments experience.

3. Materials and methods

The objective of this study was to propose a systematic literature review of the use of biometric devices for assessment in Immersive Environment (or virtual environment) experiences. We performed a qualitative and systematic literature analysis using VOSviewer software (www.vosviewer.com). In this process, five filters were applied to narrow the number of publications found.

Table 1: Search parameters.

Field	Option
Keywords	TITLE-ABS-KEY ("immersive environment" OR "virtual environment" OR "immersive" OR "mixed reality" OR "virtual reality" OR "augmented reality") AND ("Biometric" OR "Physiological")
Search in	Title, abstract, keywords
Period explored	From 2000 to 2020
Type of documents	Articles and conference papers
Database	Scopus®

Filter 1. First, we searched in the Scopus database articles and conference papers from 2000 to 2020, using the title, abstract and keywords fields. The 20 years period was chosen because as analyzed from the (Dupont et al., 2018) research it was appeared that before 2000 there are few research works on the immersive experience assessment question. The search parameters are presented in Table 1, the search equation used the keywords: Immersive environment (or Virtual) and Biometrics (or Physiological).

With this first filter a total of 1850 publications were found.

Filter 2. The second step was to use the proximity operator “W/50” between the same keywords. This tip is provided by Scopus to make sure all terms appear in the same paragraph. Applying this filter 530 publications were found.

Filter 3. Using exclusion criteria of English publications and excluding duplicates, a total number of 513 publication result.

Filter 4. Then on this step, we read and analyzed the abstracts of the 513 selected articles, for a quantitative analysis. After the screening 153 publications were chosen as the most relevant, because there were several works unrelated to immersive environment from the previous filter. In addition, we excluded papers performing literature reviews, using languages different from English and we maintained application studies using biometrical devices in Virtual environments. Those 153 selected papers were carefully reviewed and classified to the category of biometric devices used (common technology, original technology and non-typical technology), classified by their study objectives and classified according to the properties of the ICE structure (cf. Appendix B).

Filter 5. This filter based on reading and analyzing the abstracts of those 153 selected articles, for a quantitative analysis, 26 publications were chosen. This filter consisted in the analysis of the topics to select which of those were focused exclusively in immersion study and not for other types of applications, we identified among them the parameters to be monitored used in the immersion research.

4. Findings

4.1. Data analysis through visualization

A total of 1850 studies from the first filter were analyzed with the VOSviewer software. Using co-occurrence links, a network of keywords was developed and mapped (cf. Figure 2). The circle represents the keywords and its diameter represents the frequency of occurrence. The distance between words means the relatedness, so, the closer two words are located the stronger their relatedness.

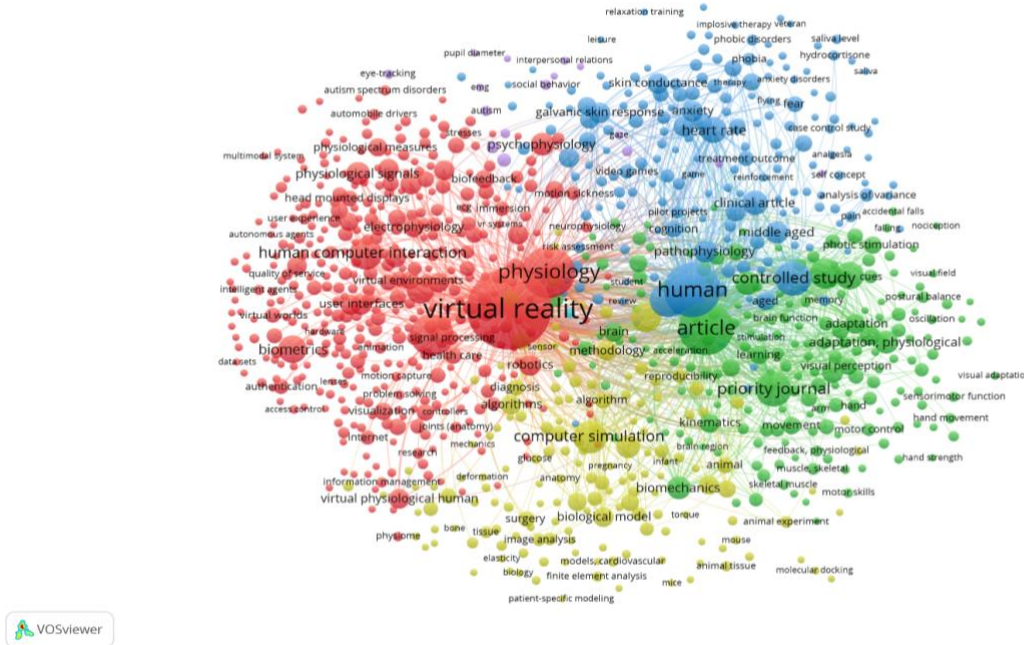


Figure 2. Network analysis of 1850 publications by VOSviewer software

In figure 2, a collection of keywords having strong relationship creates a cluster, each represented by a different color. A total of four main clusters were identified by VOSviewer. Table 2 details each cluster, color, main keywords and others related words. From table 2 we observe that each cluster might be associated with a certain research trend. The first trend represents the use of virtual environments as a tool for simulation and as an interface for simulators. The second trend shows that there is a stream of research that deals with the use of physiological responses for the study of human computer interaction. The third trend is the use of some specific commonly used variables in these studies, as heart rate, emotion, anxiety. The fourth cluster links some of the aims of the studies that were found (e.g. memory, learning or adaptation studies).

This initial analysis allows us to identify what type of studies have been performed and which types of technologies have been commonly used.

Table 2. Network analysis of 1850 publication with VOSviewer software

Cluster	Color	Main Keywords	Other related words	Research Trend
1	Yellow	Computer interface, simulation, article	Computer simulation, algorithm adaptation, software	Computer interface, simulation and article as a tool of virtual environment studies
2	Red	Virtual Reality	Human computer interaction, physiology, physiological response, biometrics	Virtual reality and human computer interaction use physiology and physiological responses
3	Blue	Heart Rate, Emotion	Psychophysiology, anxiety, attention, questionnaires, stress, arousal, self-report	Variables as hear rate, emotion, anxiety and others are variables used in virtual reality environments
4	Green	Vision, Biomechanics, adaptation, human experiment	Movement, memory, learning, adaptation	Those keywords may reflect aims or objectives of the researches

4.2. Document analysis

Based on the Filter 4 the 153 selected publications were first categorized by the application domain and aim of study. Then we performed a detailed analysis on the different technologies that were used.

In an initial analysis we identified five main categories of the aim of the studies. Most of the studies intended to understand and Improve effectiveness of virtual environment (71), a second stream was concerned with Psychological purposes (51), then studies related to Simulation to measure performance (13), then studies related to Health (12) in general and studies related to Education and training purposes (6).

4.2.1. Biometric devices used to measure Immersive Virtual Environments

On the analyzed papers biometric devices were used to measure the emotions and assess the experience of the participants in immersive virtual environments. We summarized them in three categories according to the frequency in which they have been found in the literature: common, original and non-typical technologies. Common technologies are devices that were found on at least 5 studies, original technologies are technologies that were developed for a specific purpose of the study, and non-typical technologies are technologies that were used by less than 5 studies. In particular, we observe that they correspond to existing devices or technologies but are rarely used in the context of immersion studies. Among the studies 82% of the papers used common technologies, 14% used non-typical technologies and 4% developed their own original technologies.

4.2.2. Common Technologies

In common technologies, the most used technology or physiological response to measure virtual environment was heart rate measure (89 studies), followed by skin conductance (67 studies). Other common technologies are less frequently used as respiration rate (20 studies), EEG (30 studies), EMG (9), Blood Flow Velocity (9) and Salivary Alpha Amylase or Cortisol (10). The eye tracking technology that is common in user experience studies was less common on the immersive experience studies found (8 studies).

In the case of Heart rate measures with ECG it has been commonly used with EEG to assess emotional responses and the sense of presence (Marín-Morales et al., 2019; Vogt et al., 2015). In addition, GSR and Respiration Rate measurement devices were used to evaluate emotional (Silva et al., 2009) states and as a measure of stress levels (Hägner et al., 2008; Tinga et al., 2019; Wood et al., 2007). GSR have been used in cognitive rehabilitation as an indicator of presence (Lo Priore et al., 2003; Slater et al., 2006).

Jackson et al. (2015) developed the Evolutive Virtual Environment for Empathy Improvement (EEVEE). It is based on three main components: (1) different avatars capable of expressing feelings and emotions in various levels based on the Facial Action Coding System (FACS); (2) systems to measure the observer's physiological responses (heart and respiratory rate, skin conductance, eye and eye movements, facial expression); and (3) a multimodal interface that links the behavior of the avatar with the neurophysiological response of the observer. EEVEE consists of a series of devices that will allow real-time measurement of the behavioral and physiological responses of the participants, using biometric devices such as: Face Reader (Noldus) as an emotional face recognition tool to create avatars. In addition, they used measures of heart activity, respiration rate, and skin conductance, as well as eye-tracking and pupillometry.

In the case of eye movements they have been used as a predictor of emotional states and to assess the effects in virtual reality context (Cebeci et al., 2019). Other authors, have used eye tracking as a tool to improve the collaborative immersion experience. Murray et al., (2009) studied how the gaze is of paramount for subjects to correctly identify what a person is looking at in an immersive virtual environment. For this, they tested the differences observed when a subject tried to distinguish which objects in a scene looked at the avatar in the environment. As a result, they find that Eye-gaze has proven to be a key resource for collaborative interaction. In addition, eye-trackers were commonly used as attention, visual search and visual memory indicators in Immersive Experience (Kit et al., 2014).

4.2.3. Original Biometrics Technologies

In the case of original technologies different types were found. GNeuroPathy, Deep Long Short-Term memory (LSTM) and Multimodal Biofeedback System. GNeuroPhaty was a technology developed to measure

electrodermal response in virtual reality (Quaresma et al., 2019). LSTM was developed to record state postural signal (Hofmann et al., 2018). Multimodal Biofeedback was designed to capture up to six biomedical signals: EMG, EEG, GSR, temperature, heart rate and respiratory rate simultaneously. Other developed technologies were found: Virtual Reality Medical Center (VRMC), Integrative system, Foveal Eye movements, eyeblink potentiation, Ear-Eye Pitch (E2P), PhysioVR, OpenViBe.

Quesnel & Riecke (2018) studied interactive virtual reality as a positive technology that can generate astonishment and how the scale of beauty / aesthetics, familiarity and personalization characteristics (self-selection of travel destinations) can induce astonishment. To measure the physiological response related to the incredible emotional experience, they created a "chicken-skin camera" that consisted of a webcam to capture changes in skin texture. The person uses the device on his non-dominant arm and was designed to accommodate virtual reality manual controllers. The video of the camera was analyzed to determine the presence of goosebumps on the skin.

It is still complex to measure facial expressions in the virtual environment, because the use of HMDs covers the person face. However, Burn (2017) has developed a device called MASK, a base in foam sensitive to neurons that comprises a ring of sensors that can be inserted in the front plate of any VR headset. This biometric technology allows to detect the user's facial expressions and translate the emotion expressed through virtual avatars in real time.

4.2.4. Non typical biometric technologies in VR

In this category we identified existing technologies that are uncommon to be found in virtual or immersive environment studies. However, they are common in other fields of study such as medicine, biology, neuroscience or others. These were used in these virtual studies mainly because the variable studies were very specific, so they integrated different tools from other areas of knowledge, such as neuroscience (Alcañiz et al., 2018). We found the use of oxygen consumption (VO₂) was used in 3 studies, accelerometers (2 papers), mean ventilation responses (1 paper), body forces (1 paper), transcranial Doppler (1 paper).

Blood flow and oxygen consumption was used in anxiety studies while salivary measures to cortisol (Stress) studies. Among the studies that used a non-typical measures (Yu et al., 2018) created a health application that uses VR and biometric measurements. The objective was to examine the influence of forest and urban environments of virtual reality on health. To measure the impact of the VR environment three biometric measures were used: heart rate frequency, salivary α amylase activity, to quantify stress levels. It was measured using a salivary amylase monitor DM-3.1. Additionally, participants Blood Pressure was used to detect the right position of participants' arm or movement it was measured by blood pressure monitor (HEM-1000).

Other studies focused on comparing the immersive environment and the real environment based on other physiological responses. Yeom et al., (2019) focused their study on determining whether a thermal quality component and a component built in a built environment could generate some physiological problems, compared to the real-world environmental condition. For this, they used a biometric temperature sensor (STS-BTA).

4.3. Use of properties from the ICE structure

Based on the 153 publications from Scopus we classified the properties studied in each publication quantitatively in the ICE structure (cf. figure 3 and appendix B).

From the 153 publications, only 39 of these studies used at least one of the properties proposed by the ICE structure. Most of the properties from the ICE structure that were used by the studies are those related to emotional immersion facet, being Attention and Presence the most studied properties.

A final filter (Filter 5) was applied to select twenty-six studies that exclusively focused on immersion research. We found that 20 (77%) articles from the 26 used at least one of the properties proposed in the ICE tree structure. From the 26 analyzed studies 58% used only properties found in the ICE structure, 23% used some of the properties in the ICE structure but combined them with other properties, and 19% used only properties that are not included in the ICE structure. Among the other variables included in immersion studies researchers used anxiety (in 3 studies) and stress (2 studies). In terms of parameters to be monitored to assess the different

properties that affects the immersive experience figure 3 synthesis the results related to the technologies and properties of the ICE model. Appendix B presents the technologies used for parameter monitoring in all the papers. As presented previously it is shown that heart rate, respiration rate and skin conductance measure are the most used technologies. The Self-presence property of is the one that has benefited from a higher development and use of parameter monitoring technologies followed by Attention property. It would be interesting to see further development of technologies to assess the other properties.

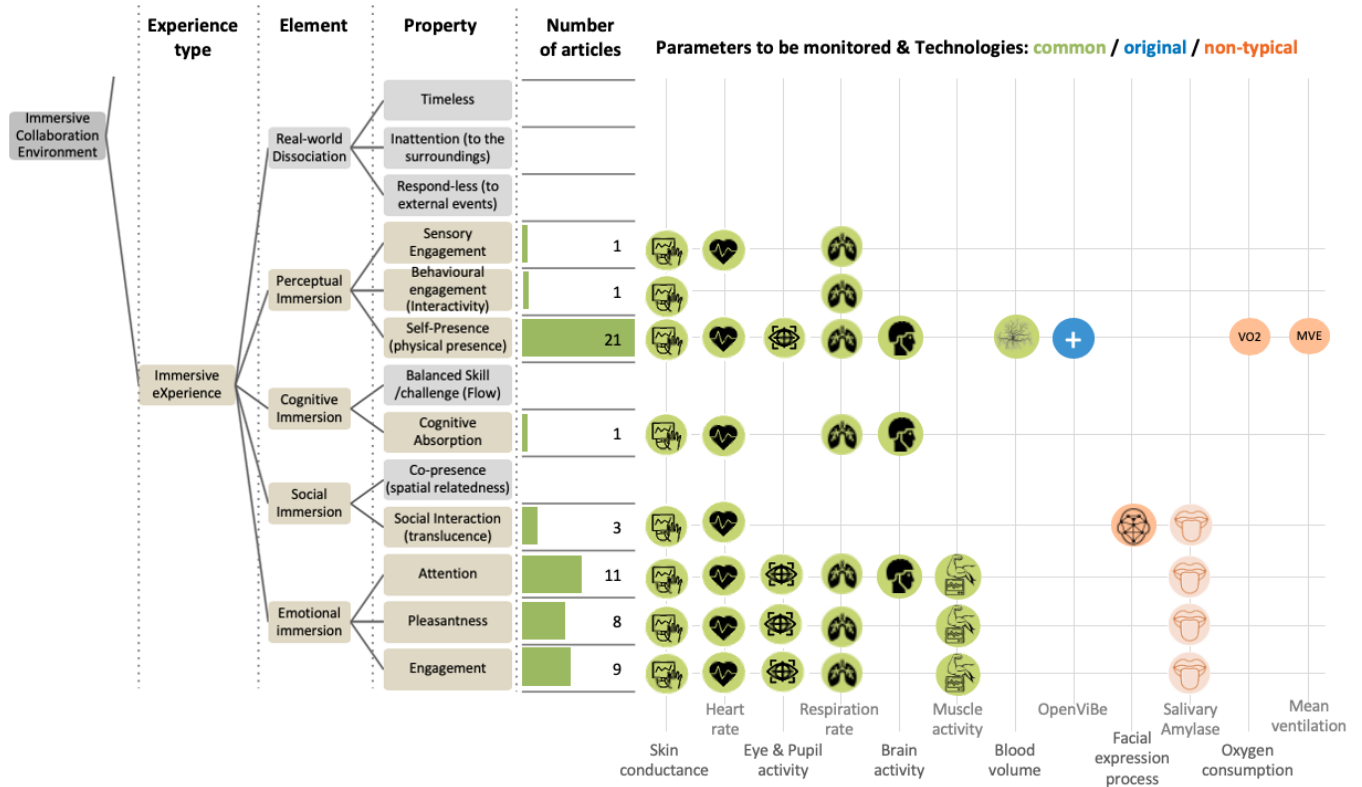


Figure 3. IX Properties and technologies found in the analyzed studies

5. Conclusion

For this study, a systematic literature review methodology with five filters was used to narrow down the number of potential articles collected from the Scopus database. An initial search presented 1850 publications for uses of biometric/physiological devices to measure virtual environment that were briefly explored. In an additional filter we narrowed them down to 153 to develop a qualitative analysis. This literature review contributes to mapping links and connection of the uses of biometric devices in Virtual Environments and some categories of their uses.

To measure immersive environment's experience many studies used biometric or physiological approaches. Their aim was mainly on improving the efficiency of the developed platforms.

Regarding technologies, heart rate and skin conductance were the most used physiological assessment devices used in virtual environments. However, in this review we presented some other non-typical and original technologies to evaluate virtual environments such as blood flow and salivary measures.

Our initial aim was to understand how the physiological technologies have been used for assessing properties and facets of the immersive dimension of ICE tree structure, in order to facilitate the use of the ICE tree model in assessing immersive experiences in complementarity of the already employed questionnaire and survey instruments. From the analyzed studies we observe that 8 of the properties included in the model have been evaluated by a biometrical approach. The most commonly assessed property is presence, as an indicator of immersion. Additionally, it was found that previous research in immersion studies have used Anxiety and Stress properties as an indicator of immersion. These two properties are not part of the ICE tree model, but this shows that further research should explore the inclusion or not of these properties for example to consider them in the Emotional aspect facet.

Additionally, we found that the availability of biometric tools coincides with the most studied properties or explained in another way, those that have been studied the least are the ones that have less biometric tools available according to what we saw in the review. This represents a great opportunity not only to study the variables proposed in the ICE but also to develop or propose physiological tools that will allow them to be studied.

This review is not without some limitations, it is only a partial view of the existing literature the presented annexes and list of papers are the base that need to be enriched by a deeper qualitative analysis on the uses of the physiological devices and their use constraints. To operationalize the uses of the devices to assess the different properties we need to consider the multifactorial dimension of the parameters monitored, the interpretation of the potential collected data will be a challenge.

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Appendix A. List of papers from the literature review

Ref	Detail
1	Jang, D. P., Kim, I. Y., Nam, S. W., Wiederhold, B. K., Wiederhold, M. D., & Kim, S. I. (2002). An investigation of immersiveness in virtual reality exposure using physiological data. <i>Studies in Health Technology and Informatics</i> . https://doi.org/10.3233/978-1-60750-929-5-207

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Appendix B. ICE structure properties present in the literature papers.

SkC	HR	RR	EyeT	EEG	SkT	BFV	EMG	SAA	GNP	VRMC	INTS	FE	EBP	PVR	PP	OViBe	BF	VO 2	MV E	FR	ACC	TCD
Skin conductance	Heart Rate	Respiration Rate	EyeTracker / ocular exploration	EEG	Skin temperature	blood flow velocity (BFV)	EMG	salivary alpha amylase or cortisol	GNeuro Pathy	VRMC	INTS	Foveal Eye	Eyeblink potentiatio	PhysioVR	Photoplethysmography	OpenViBe	Body forces	oxygen consumption	Mean ventilation responses	Facereader	Accelerometers	transcranial Doppler

Ref	Immersive eXperience										Common Technology										Original Technologies										Non-Typical Technologies							
	RwD			PI			CI	SI	EI			SkC	HR	RR	EyeT	EEG	SkT	BFV	EMG	SAA	GNP	VRMC	INTS	FE	EBP	PVR	PP	OViBe	LSTM	MBS	BF	VO2	MVE	FR	ACC	TCD		
	RwD	RwD	RwD	PISE	PIBE	PISP	CIFA	SICp	SISl	EIA	EIP																										EIE	
1				X								X	X	X			X																					
2						X						X	X				X																					
3												X	X				X																					
4						X																																
5												X	X																									
6						X							X																									
7									X	X	X	X	X	X			X		X						X													
8									X			X	X																									
9						X						X	X																									
10												X	X																									
11									X					X																								
12						X						X	X																									
13												X																										
14									X			X																										
15						X						X	X	X				X																				
16												X																										
17													X		X																							
18						X																																X
19						X						X		X																								
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