Virtual Reality
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ORIGINAL ARTICLE

# The relationships between the exploration of virtual space, its presence and entertainment in virtual reality, 360º and 2D

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## Abstract
This research investigates the relationships between the way virtual space is explored, the perception of presence and the degree of entertainment experienced during the experience. All participants ($N = 147$) interact with an omnidirectional video clip in three different conditions (VR, 360º, 2D). Throughout the two experimental sessions, affective, cognitive, and behavioural information is collected from the participant, which allows us to relate their interactive behaviour, their perception of presence and degree of entertainment. The possible influence of experience with interactive systems on current interactive behaviour is also analysed. The results highlight the complex relationships between these nuclear dimensions of VR and indicate the existence of two types of exploratory behaviour that we have called *interface dependent* and *interface independent*. When the first is present, there is no connection with the positive perception of presence and entertainment, but there is in the second. This typology shows the need to consider the learning processes in the access to the content through the interface in digital interactive systems such as VR and 360º.

**Keywords** Virtual Reality · Virtual Space · Presence · Entertainment · Navigation

## 1 Introduction

One of the ways to advance in the knowledge of virtual reality (VR) is to investigate the processes of interactivity with the device and the psychological effects that these induce in the user.

Exploring virtual space is one of the most prominent components of the interactive user experience. From a psychological point of view, a second aspect of VR interactivity is the perception of *presence*. The analysis of the exploration of the virtual space and the perception of presence informs us about what happens during the interaction with the device, but it is also necessary to know why and for what purpose the user can decide to dedicate time to navigate in a virtual scenario. In some cases, VR is a useful tool at the service of engineering, aeronautics, or medicine, in others, it is at the service of teaching/learning, in others it is a cultural recreational product. In the latter case, users seek to obtain from the interaction an experience of enjoyment. Consequently, the user experience in recreational VR includes a third entertainment factor, which we need to investigate to improve our VR designs and better understand the user behaviour.

We currently know a lot about the perception of presence in VR and 360º video and entertainment in digital environments in general, as well as in VR, 360º and traditional video (2D) (Hartmann and Fox 2020). However, we know little about how the user who interacts with a virtual space, explores that space in different environments such as VR and 360º, and what the characteristics of that exploration are. At the same time, the relationship between that exploration and its relation to the perception of presence and the degree of entertainment experienced by the user interacting with that virtual environment has not been investigated. Consequently, the general objective of this research is to investigate the characteristics of the user's exploration of virtual space and its relationship with presence and entertainment. For this reason, we will first specify the notions of space exploration, presence, and entertainment in VR and then delimit the way to approach the study of their relationships.

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## 2 Virtual space, presence and entertainment in VR

### 2.1 Virtual space

The notion of virtual space is a transdisciplinary concept that encompasses different perspectives combining science, technology and culture (Wideström 2019). The virtual space referred here corresponds to spherical videos with omnidirectional content (Wu and Lin 2018; Rossi et al. 2019). These videos depicted an immersive virtual reality environment. As Kien points out, the term "virtual environment" is usually described as a form of human–computer interaction (HCI) consisting of a computer-generated visual and audio simulation of three-dimensional space (i.e., a 3D graphic), in which users have interactive experiences (i.e., they communicate with one another and/or have the ability to respond to or alter the aesthetic experience of the environment, such as controlling the movement of an avatar or changing some characteristics of the environment). (Kien 2009:11).

Two fields of study of virtual space can be distinguished (Wideström 2019). One is interested in the *technological design variables* that allow better exploration of virtual space. In another field of study, the *behaviour of the avatar and the subjects* is analysed. For example, while the user watches omnidirectional videos in a task-free scenario, it measures the user's field of view. That is to say, the part of the video which is being viewed by the user at any given time (Mahzari et al. 2018). Other studies analyse the yaw and pitch angles (Fremerey et al. 2018; Nasrabadi et al. 2019), the user navigation patterns (Rossi et al. 2019), orientation (Sheikh et al. 2016; Tenbrink and Salwiczek 2016; Pavel et al. 2017) or also the head direction trajectories (Upenik and Ebrahimi 2017). These series of studies have allowed us to us to start studying navigation and exploration in a virtual environment and provide knowledge of interest to developers. But many questions remain about what happens during the interactive process in that virtual space and what psychological effects it produces. One of them is the perception of presence.

### 2.2 Presence

The concept of *Presence* is related to some close concepts like *immersion*, *perceptual immersion* (Lombard and Ditton, 1997 in Kuksa and Childs 2014:7), *embodiment* (Biocca 1997; Kilteni et al. 2012; Gonzalez-Franco and Lanier 2017; Hartmann and Fox 2020), *spatial presence* (Lee 2006), co-location (Hartmann and Fox 2020)(Hartmann and Fox 2020), *telepresence* (Biocca 1997; Hartmann et al. 2010), *social presence* (Lee 2006), *cognitive distancing* (Hartmann 2011; Quaglia and Holecek 2018). There are studies that analyse the static or dynamic spatial perception (Ikeda et al. 2015) of simple objects. It is also the case in studies of spatial abilities in virtual space that measure of mental rotation, location and memory of objects in space (de Castell et al. 2019). Among the few studies that have studied user behaviour in the virtual environment, there are fewer that analyse that navigation in entertainment products. In the framework of the present investigation, we will be interested in the spatial presence, the users' experience of "being there" in the virtual setting (Lee 2006; Hartmann and Fox 2020). Hartmann et al. (2016), consider that the spatial presence is a specific construct of a broader class of presence phenomena. For these authors, spatial presence focuses on "spatial illusions" and can be distinguished from social presence and transportation. The way Hartmann et al. (2016) use the spatial presence construct refers to the same user experience that others terms "physical presence" (Lee 2006) or telepresence (Draper et al. 1998). Wirth et al. (2007) base their conception of the Spatial Presence on a two-level model of the formation of spatial presence which proposes that people first generate a mental representation of the physical space that is presented, and after that, they activate and test perceptual hypothesis that concern the acceptance of the mediated space as the primary frame of reference (Wirth et al. 2007). This conception of spatial presence by Wirth et al. (2007) and Hartmann et al. (2016), as the interest to include in its evaluation the measurement of the "spatial illusions" through the self-location and perceived possible actions scales. These two dimensions allow to raise the possible hypothesis of its relationship with the exploration of the virtual space. The question is whether the sensorimotor exploration of the user's virtual space contributes to the formation of spatial presence or whether it is formed simply through mental representation. This question will be addressed in this investigation.

### 2.3 Entertainment

A second psychological effect of VR interaction is the degree of entertainment experienced by the user. Entertainment is a multidimensional reception phenomenon with motivational, emotional, and effect relevant aspects (Vorderer 2003; Eden 2017). Although, to date, an integrative conceptual framework, a number of key affordances and characteristics of the VR experience have recently been proposed that can shape the entertainment experience (Hartmann and Fox 2020). VR engages the sensorimotor system in a different manner than other media (e.g., motion, spatialization) and mapped modes of interaction using head rotation, gestures, and body movement. Given the way VR engages the sensorimotor system, VR can make users feel like they are having "a non-mediated primary experience of the everyday world" (Frey 2018, p. 495). In short, Hartmann and Fox, VR can feel more "real" than other channels (Hartmann and Fox 2020, p. 4). From a cognitive standpoint, the VR entertainment experience is fueled by several factors: *embodiment*, that is to say, the body-transfer illusion (Gonzalez-Franco and Lanier 2017), refers to the extent users experience the body of their virtual representation, or avatar, as their actual body or an extension thereof (Ratan and Dawson 2016). The embodiment promotes feelings of identification (Klimmt et al. 2009). The *spatial presence*, which we have defined above, is a second variable that induces entertainment and is a concept linked to the embodiment (Haans and IJsselsteijn 2012). Also, the *co-location*, defined as users' subjective perception that displayed entities are physically co-present and seemingly tangible (Hartmann and Fox 2020), contributes to entertainment. From an emotional point of view, since the user is immersed in a "hyper-reality", VR triggers both physiological and attitudinal responses that may be more intense than in less realistic or less immersive environments (Lang 1990; Seo et al. 2017).

## 3 Objectives and hypotheses

The user experience with digital interactive media provides a series of sensory cues, which include the perception of virtual space that the user explores as he or she interacts with the device. These interactive actions are accompanied by a subjective perception of presence, as well as an evaluation of entertainment induced by that experience. Virtual space, presence and entertainment are therefore three key concepts in the experience in interactive environments. This triple experience is not only influenced by the interactive possibilities of the device but also by the way the interface presents the virtual world through one or another technology (Seibert and Shafer 2018). Therefore, this research raises the following set of research questions and hypotheses:

**RQ1** (research question): Whether there are differences in virtual space exploration, presence, and entertainment in VR, 360º and 2D and what those differences are. We propose the following hypothesis:
**H1.** The exploration of virtual space (EXES), the perception of presence (PRE) and the degree of entertainment (ENT) is different in VR, 360º and 2D.
**RQ2: To** Investigate the relationships between the exploration of virtual space, presence, and entertainment. Three hypotheses:
**H2**. There is a relationship between Virtual Space Exploration and the perception of Presence (EXES PRE).
**H3**. There is a relationship between the exploration of Virtual Space and the Entertainment experienced (EXES ENT).
**H4**. There is a relationship between the perception of Presence and the Entertainment experienced (PRE ENT).

**RQ3:** To investigate the influence of previous personal experience in VR, 360º and interactive media on space exploration, entertainment, and presence. Hypothesis:

**H5**. The previous experience with digital interactivity [(EXP) (GAMER)] influences the exploration of the virtual space, the degree of entertainment and presence [(EXES) (ENT) (PRE)]

**RQ4:** To inquire about interface preferences and interactivity in VR and 360º after participating in the experience.

**H6**. After the VR and 360º experience, participants prefer (COM) the VR over the 360º, value their interactive experience (INTER) in VR better, perceive greater ability to interact with content (PAP) in VR and feel less frustration (FRU) when using the VR interface than the 360º (VR: COM, INTER, PAP) > (360º: COM, INTER, PAP) and FRU-VR < FRU-360º).

## 4 Method

Comparing the same content in a VR and a 360º device allows us to investigate the influence of the display on space exploration. This exploration, conditioned by the properties of the interface, is an interactive process that provides information about the behavioural interface. This includes variables linked to the sensorial interface, the motor interface and the sensorimotor interface (Fuchs 2017). In advanced VR devices, the user moves in a virtual world that allows them to perform a space exploration that includes three-dimensional axes and where the objects located in that virtual space provide bidirectional information (as a device with force feedback interface, with which the user receives haptic information from the virtual objects). The sensory, motor, and sensorimotor variables involved in these advanced VR devices are numerous and complex and prevent a comparison with the 360º. Since some of these variables are not present in the 360º video and, therefore, being able to influence the exploration of virtual space, they would not allow a comparison between the exploration of virtual space in VR and 360º under the same conditions.

The knowledge of the psychological aspects of the exploration of virtual space is far from being known in depth and given the considerable degrees of freedom present in advanced VR devices. It is convenient to use a VR device that allows comparison with other interfaces (such as 360º), taking into account that the same variables and axes of space exploration (EXES) must be able to be measured in a virtual environment with comparable degrees of freedom of exploration in both devices.

## 4.1 Materials

The VR group uses as head-mounted display (HMD) a HTC Vive. This group play the video in the YouTube application of Steam, with a resolution of 4 K to resemble a playback in a home use. In the 360º and 2D groups, the video is played on a 24" screen at a resolution of 1920 × 1080px at 50 frames per second. The software used was the Mozilla Firefox browser, and the YouTube web player. So that the control and the reproduction are equal to those of any domestic use with a desktop computer. In the 360º group, mouse and keyboard were used to control the movement. To ensure correct playback in all groups, the sound of the video clip is received with ASUS Strix headphones. The playback of each video is recorded from the computer itself in the VR group and by external video capture in the other two groups.

In this research we used the same entertainment product for the three experimental groups. The video used is "[360º Music Video] *This Summer-Roomie* (Maroon 5 Cover)" (https://bit.ly/32gtmjD). It is a music video where its protagonist (the youtuber Roomie) serves as the centre of attention and reference for the viewer by not changing position between one shot and another. Although it does so slowly within the same shot, gradually encouraging the viewer to explore the space with him. This video can interact with the subjects in 360º with high quality and using an HMD. A second advantage is that the degrees of freedom in the exploration of the two EXES axes are the same rotation displacements in the omnidirectional space. A recent study by Nasrabadi and collaborators (2019) has made a taxonomy of 360º video as a function of camera movement and objects on stage. In our case, the video clip used is located in a virtual environment that is not as restrictive as those studies that analyse only objects or specific locations (such as the research of Dorado et al. 2019) or too open and free spaces (task-free scenario) as it happens in many video games. There is, at the same time a concrete fixing point, a concrete target (the singer) but, at the same time, a stage that allows an omnidirectional exploration. This localized virtual space, from the user's field of view, as it is initially common to all users and, at the same time, is an open space that allows each user to freely choose their omnidirectional exploration (that is to say, to explore the 360º of the video, being able to leave the viewport pattern that induces the tracking of the singer). This allows comparisons to be made between subjects and a search for an objectifiable pattern of exploration in terms of measured variables. On the other hand, the interest of using the video clip is that, from the point of view of the objects on stage, which as Nasrabadi et al. (2019) shows, allows to classify the videos, On the other hand, the interest of using the video clip is that, from the point of view of the objects on stage, which as Nasrabadi et al. (2019 shows allows to classify the videos, we always find the singer as the central element of each scene, which allows to compare the evolution of the exploration along the nine scenes that conform the video clip. Therefore, any differences we may find between VR and 360º will be due to the influence of the properties of the device on the psychological perceptions of presence and entertainment.

## 4.2 Study design

Participants were 147 undergraduate students recruited via communication courses laboratory and they were offered extra credit for their participation. The gender breakdown for the sample was 57.1% female ($n = 84$) and 42.9% male ($n = 63$). Average age was 21.5 years. Via random assignment, 36.7% ($n = 54$) of participants were assigned to the VR condition, 32.6% ($n = 48$) were assigned to the video 360º condition, and 30.6% ($n = 45$) to the 2D condition.

## 4.3 Instruments of measurement

Previous research indicates that the viewer's vision usually follows the line of the horizon, unless there is some point of interest that might draw his or her attention to the bottom or top of the plane (De Abreu et al. 2017; Corbillon et al. 2017; Duanmu et al. 2018; Mahzari et al. 2018; Nasrabadi et al. 2019; Wu et al. 2017; Fremerey et al. 2018). In addition, some studies indicate that if the user directs his attention to the upper or lower parts, he does so for a short period of time in order to continue watching the video in the horizon area, which is a more comfortable position (Fremerey et al. 2018). Considering this research background, in the present study, we measured the visualization of horizontal space, as the points of interest are close to the horizon line. The 360º video of this investigation has nine shots. We have divided the omnidirectional space into four quadrants (cf. Figs. 1, 2: front, left, right, back). This allows us to know when the subjects stop looking forward or towards the point of interest which is the youtuber itself, when it is not in the front quadrant. According to the research of Fremerey et al. (2018), 50% of subjects maintain most of their gaze at 30° to the right or left of the starting point in a yawing motion. In pitch, it is even 90%. Viewers usually keep looking straight ahead,

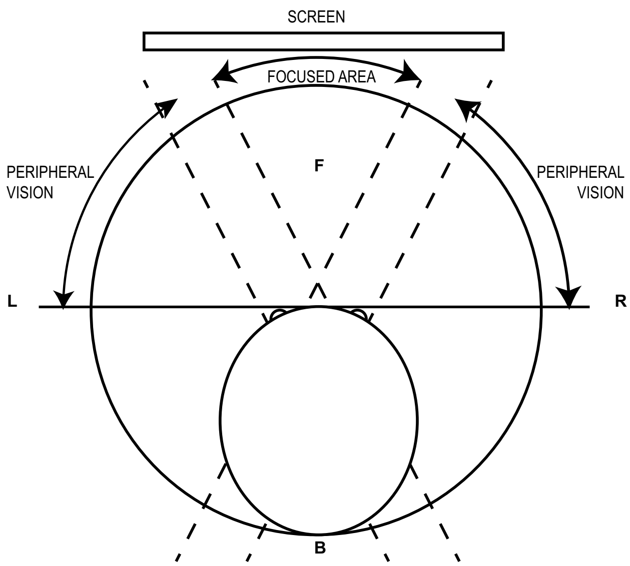


**Fig. 1** Omnidirectional space quadrants

unless some element of the action makes them look in another direction (Fremerey et al. 2018). Google emphasizes this same fact as an advice when creating 360º videos for YouTube by presenting the analysis tool included in the platform (YouTube 2017). Therefore, with the video used in this research, the analysis of horizontal space is a good indicator of the subject's spatial exploration and allows comparisons with other psychological processes that take place during the interactive experience.

There are five types of measuring instruments:

1. In VR and 360º, the *exploration of virtual space* (EXES) performed by the subject in each of the nine sequences is recorded. The total number of spatial movements of the subject (head rotation) in the set of quadrants, as well as the distribution of visits in each of the quadrants explored, is counted. In 2D, the subject does not have the possibility of making spatial movements or deciding about the quadrants to explore. He cannot explore virtual space (EXES). His processing of space follows the orientation and rhythm foreseen in the video clip. In this sense, he has a forced and linear exploration that is determined by the closed technology of video with whose virtual space he cannot interact.

This space has the general properties of music videos where the camera follows the singer in priority. As suggested by the previous research cited at the beginning of this section (De Abreu et al. 2017; Corbillon et al. 2017; Duanmu et al. 2018; Mahzari et al. 2018; Nasrabadi et al. 2019; Wu et al. 2017; Fremerey et al. 2018), in this type of situation, the subject visually follows the singer who constitutes the point of interest. The singer occupies the central focal part of the frame and the horizontal line of the frame.

In short, in the 2D group, there is no exploration of virtual space (EXES). However, including the 2D group in this research has the interest of allowing us to investigate whether this absence of exploration of the virtual space, with respect to VR and 360º, has as a consequence a less presence and less entertainment. This result would help to underline the importance of interactivity and the exploration of virtual space in the enjoyment of cultural entertainment products.


**Fig. 2** Shots 1 and 5 of the videoclip and its four quadrants in planar representation

2. *Presence* is measured by The Spatial Presence Experience Scale (SPES) in its two subscales, self-location (SL) and possible actions (PA) (Hartmann et al. 2016).
3. *Entertainment* is a multidimensional phenomenon; therefore, several scales have been used to obtain complementary information on various dimensions linked to entertainment:

   - **PANAS**: In the present research, it is interesting to know if the experience improves the participant's affective state and if this eventual improvement differs between VR, 360º and 2D. To measure this aspect, we use the I-PANAS-SF scale (Thompson 2007; Gargurevich 2010; Karim et al. 2011; Merz et al. 2013).
   - **AROU**: Secondly, the process of interactivity of the participant during the experience is likely to induce arousal, which is one of the dimensions of affective states linked to entertainment (Lang 1990; Zillmann 2008). We use the Arousal scale (Bruner 2009). The scale is typically composed of six semantic differentials that are intended to measure one's arousal-related emotional reaction to some stimulus in the person's environment.
   - **AFRE**: We have also measured the Affective Positive entertainment response provided by the experience. The scale AFRE (Bruner 2009) is composed of three semantic differential items (seven-point response format) measuring one's affective response to some stimulus (pleaser, liking, feeling)
   - **ATV:** attitude toward the videoclip (scale adapted from Chattopadhyay and Basu 1990). This five-item scale asks the subject if they liked the video clip, if they found it pleasant, good, entertaining and if their attitude towards it is favourable.
   - **ATMU:** Finally, the Attitude Toward The Music of videoclip has also been measured, after being exposed to the experience (**ATMUB** scale) and before (**ATMUA)** (Tussyadiah et al. 2018). The tastes and musical preferences of the participants have also been measured (**PREMU**).

4. Information has been collected on some moderating variables related to RQ3 (H5):

   - EXP: A two-item scale that asks about the participant's previous experience with VR and 360º.
   - GAMER: scale that investigates the participant's past and current experience with interactive entertainment devices such as video games.

5. Finally, with respect to the RQ4 (H6) the following scales and questionnaires have been included:

   - COM: At the end of the experience the participant is asked to compare his experience with the two VR and 360º interfaces. They must indicate which one they liked best and explain why.
   - INTER: During the experience the subject had swept through the video clip with the HMD or the keyboard and mouse in 360º. In a double three-item scale, the participant is asked to rate both interfaces on a scale of 1 to 5 points according to whether the interaction was easy for him, whether it allowed him to move freely within the video clip, and whether it was comfortable for the participant.
   - PAP: On this one-item, five-point scale, the subject is asked to evaluate the extent to which you felt you could successfully navigate the video clip in the experience (with HMD and 360° with keyboard and mouse)
   - FRUS: This one-item, five-point scale asks about the degree of frustration the participant has experienced due to the use of the interface (with HMD and 360° with keyboard and mouse).

### 4.4 Procedure

Two sessions are conducted. At the beginning of the first session, the participants are informed about the procedure of the session, they are asked for some information and fills in some scales (PREMU, EXP VR/360º, GAMER, PANASPRE, ATMUB). Then, they interact with the video clip according to their experimental group (VR, 360º, 2D). Finally, in a second computer, them fills in the PANAS-POST, AROU, AFRE, ATMUA, ATV, PRE scales. The session takes place in the LipsiMedia Laboratory (University of V.), equipped with individual stations. During the session, each subject's interaction with the video clip is recorded. In the second session, the participants of the VR and 360º groups interact with the video clip, as they did in the first session, but now with the interface they had not used in the first session. They then complete the COMP, INTER, PAP and FRUS scales and questionnaires. The participants of the 2D group see a linear playback of the video clip on the screen.

## 5 Results

To test the hypotheses, we have organized the analysis of results into four subsections. In the first two, we have verified whether or not there are differences in the exploration of virtual space, presence and entertainment in the different devices (H1), as well as the possible relationships between these three factors (H2-4). Next, we have explored the possible influence of previous personal experience with

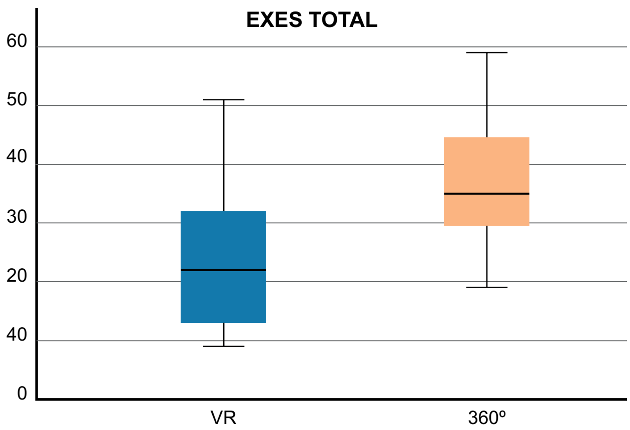


**Fig. 3** Number of quadrants of the virtual space explored in the VR and 360º groups (EXES-Total)

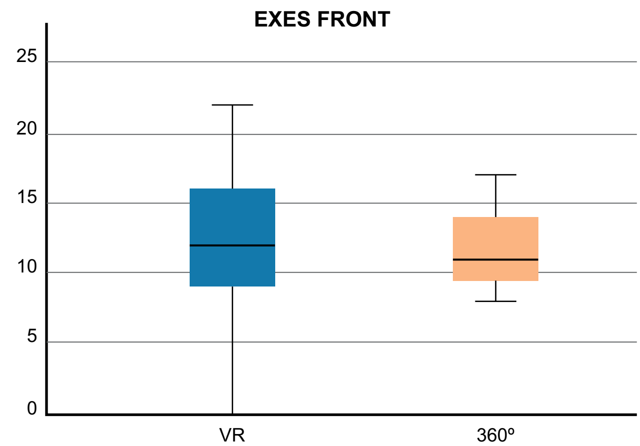


**Fig. 4** Number of front quadrants explored in the VR and 360º groups (EXES-Front)

interactive media on the exploration of space, the degree of entertainment and presence (H5). Finally, in the fourth subsection, we describe participants' preferences about interfaces and experience of interactivity after participation in the research (H6).

## 5.1 The differences in virtual space exploration, presence, and entertainment in VR, 360º and 2D

First, there are significant differences in the exploration of virtual space (EXET). As shown in Fig. 3, the average total number of quadrants scanned in the 360º group (M = 37.39; SD = 10.09) is higher than the VR group (M = 23.68; SD = 11.60). The t test for independent samples shows that these differences are significant ($t(107) = -5.77$, $p < 0.05$). To deepen these differences, the space exploration of each of the four quadrants has been analysed (cf. Figs. 4, 5, 6, 7). The independent t-sample test shows that the exploration of the space between VR and 360º in the front quadrant is not statistically significant but it is in the other three quadrants (Front: $t(107) = 1.40$, $p = 0.163$); Left: $t(107) = -5.08$, $p < 0.001$; Right: $t(107) = -4.60$, $p < 0.001$; Back: $t(107) = -13.03$, $p < 0.001$). On the other hand, it is observed that the front quadrant receives a higher average of visits than the rest of the quadrants and the rear one the least (Front: VR (M = 12.71; SD = 3.97) 360º (M = 11.61; SD = 2.73); Left: VR (M = 4.23; SD = 4.16) 360º (M = 8.55; SD = 3.57); Right: VR (M = 5.87; SD = 4.28) 360º (M = 9.71; SD = 2.80); Back: VR (M = 0.90; SD = 1.47) 360º (M = 7.52; SD = 3.83).

Finally, in the analysis of spatial exploration, the differences between VR and 360º according to the type of exploration have also been analysed, as there are subjects who explore space little, others regular and others a lot. The participants of the VR and 360º ($n = 109$) groups have visited a total of 3006 quadrants (minimum 9 and

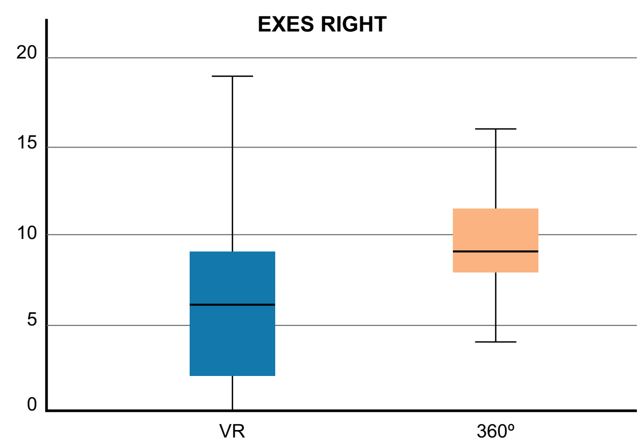


**Fig. 5** Number of right quadrants explored in groups VR and 360º (EXES-Right)

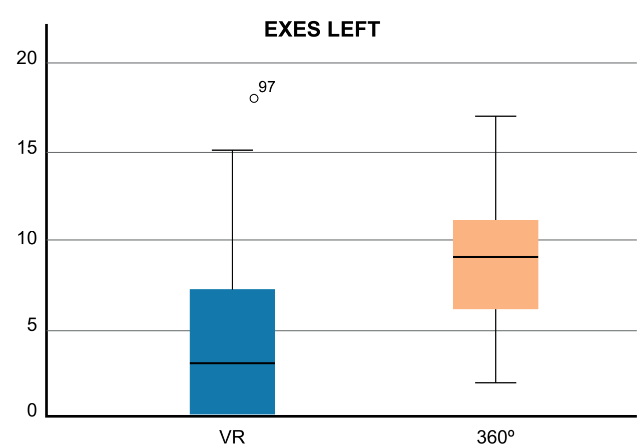


**Fig. 6** Number of left quadrants explored in the VR and 360º groups (EXES-left)

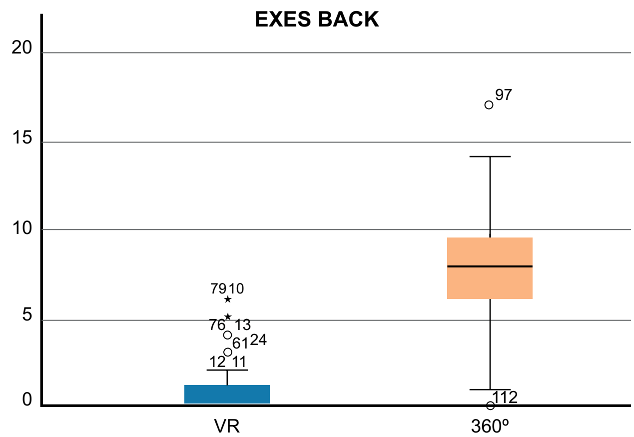


**Fig. 7** Number of back quadrants scanned in the VR and 360º groups (EXES-Back)

maximum 59; M = 27,58; median = 27). Depending on the number of quadrants visited, three groups of subjects have been defined with an equivalent number of participants. A first group, which we call static or *low*, includes those subjects who explore between 9 and 22 quadrants (33.9%); a second group, moderate or *intermediate*, between 21–33 quadrants (34.9%) and a third group, *dynamic or high*, between 34–59 quadrants (31.2%). Pearson's chi-square test shows that there are also differences between the two groups ($\chi 2$ (2, $N$ = 109) = 24.63, $p < 0.05$). In VR, static or low space exploration predominates (low $n = 36$, medium $n = 27$, high $n = 15$), while in 360º it is dynamic or high exploration (low $n = 1$, medium $n = 11$, high $n = 19$). In conclusion, space exploration is different in VR and in 360º (Hypothesis H1).

Secondly, statistical analyses show that there are significant differences in Presence. The perception of Presence is higher in VR (M = 34.35; SD = 9.10), than in 360º (M = 25.70; SD = 8.20) or 2D (M = 22.88; SD = 8.50). The ANOVA shows the perception of Presence differs depending on whether the interface is VR, 360º or 2D (F(2,144)22.836, $p < 0.001$). In Scheffe's post hoc tests, multiple comparisons show that differences between 360º and 2D are not significant (Mean difference 2.21; deviation error 2.33, Sig. 0.637), while the differences in VR with the other two groups are always significant (with 360º = difference in averages with group 360º 8.18; Deviation 1.91, Sig. 0.000; with 2D = difference in averages 10.40; Deviation 1.94, Sig.) Likewise, two homogeneous subgroups appear: one formed by VR and the other by the groups 360º and 2D. In the three experimental groups, higher scores are always obtained in the SL subscale (M = 32.20; SD = 10.70) than in the PA subscale (M = 27.55; SD = 10.28). However, the correlations of paired samples between these two subscales are very high ($r$(147) = 0.825, $p < 0.01$).

The degree of presence experienced by the participants has also been analysed. According to the SPES scale, the maximum degree of presence is 50 points. The subjects have been assigned to one of the following three categories: low (score between 10 and 23), moderate (score between 23.5 and 35.5) and high (between 36 and 50) perceived presence. As illustrated in Fig. 8, the differences between the three groups are significant ($\chi 2$ (4, $N$ = 147) = 31.94, $p < 0.05$). In VR, high presence predominates, moderate presence in 360º and low presence in 2D.

Thirdly, there are also significant differences in Entertainment between VR, 360º and 2D. As illustrated in Figs. 9 and 10, Affective Reaction (AFRE) and Attitude towards the Video Clip (ATV) are more positive in VR than in 360º and 2D (AFRE -VR: $M = 5.90$; $SD = 1.10$; AFRE -360º: $M = 5.23$; $SD = 1.24$; AFRE -2D: $M = 5.45$; $SD = 1.11$; ATV-VR: $M = 4.15$; $SD = 0.72$; ATV-360º: $M = 3.91$; $SD = 0.64$; ATV-2D: $M = 3.68$; $SD = 0.69$). According to ANOVA, these differences are significant in both AFRE ($F$(2,144)4.61, $p = 0.001$) and ATV ($F$(2,144)5.52, $p = 0.005$). On the other hand, as shown in Fig. 11, the 360º induces greater arousal (AROU) than VR and the 2D (AROU-VR: $M = 2.82$; $SD = 0.94$; AROU-360º: $M = 3.45$; $SD = 0.80$; AROU-2D: $M = 2.87$; $SD = 0.88$).

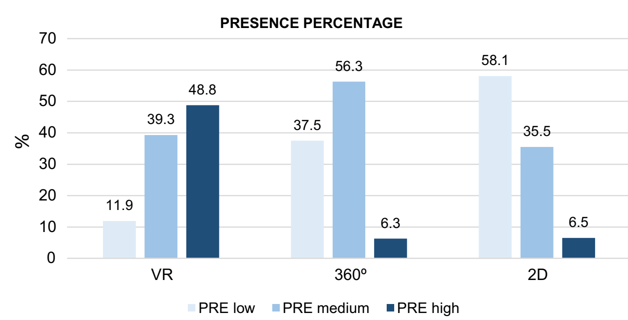


**Fig. 8** Percentage of participants who have a Low, Medium or High Perception of Presence in each of the three experimental groups (VR, 360º, 2D)

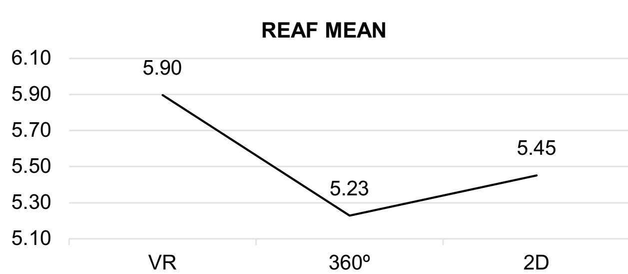


**Fig. 9** Affective Reaction (AFRE) in the three experimental groups (VR, 360º, 2D)

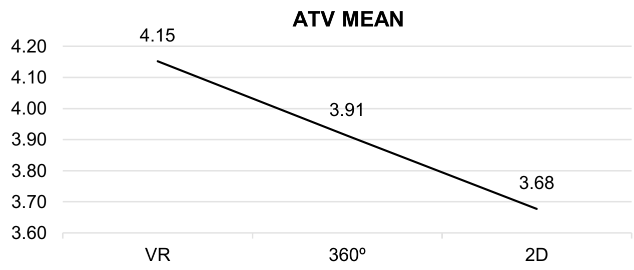


**Fig. 10** Attitude toward the videoclip (ATV) in the three experimental groups (VR, 360º, 2D)

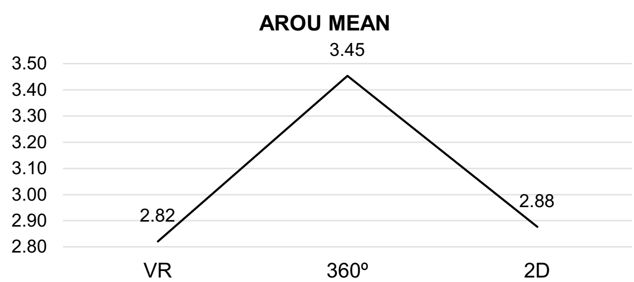


**Fig. 11** Arousal (AROU) in the three experimental groups (VR, 360º, 2D)

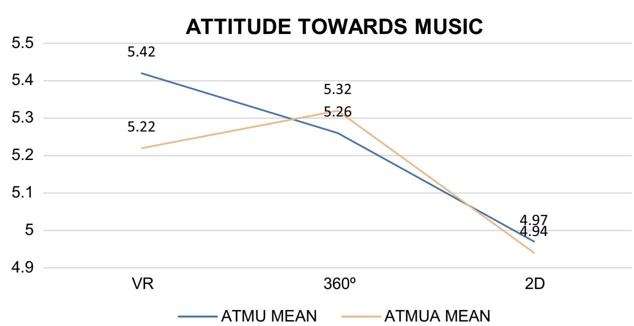


**Fig. 12** Attitude towards music before the experience (ATMUB) and after (ATMUA)

The interest of the variable Attitude towards music in the video clip (ATMU) seeks to know if there is a change in this attitude due to the influence of the interface. Before starting the test, there were no statistical differences between the three groups in this variable (ATMUB: ATMUB-VR: M = 5.22; SD = 1.13; ATMUB-360º: M = 5.33; SD = 0.94; ATMUB-2D: M = 4.93; SD = 0.99; $F$(2,144)1.17, $p$ = 0.314). After the experience, some small changes can be observed. As shown in Fig. 12, the attitude towards music is better in VR. Also, it is the only group whose attitude improved somewhat in the post-test (ATMUA-VR: M = 5.42; SD = 1.17; ATMUA-360º: M = 5.26; SD = 1.10; ATMUA-2D: M = 4.96; SD = 1.10). Although these differences between pre-test and post-test are not significant in VR ($t$(53) = -2.46, $p$ = 0.016), nor in 360º (t(46) = 0.62, $p$ = 0.536) and 2D ($t$(44) = -0.321, $p$ = 0.751), they indicate an interesting trend as they show some influence of the interface in VR that is absent in 360º and 2D. It is necessary to consider that the music is the same for all the groups, the only thing that changes is the interface. These results indicate that the experience in the virtual world provided by VR and 360º, where there is a process of interactivity, induce a more favourable attitude towards the music in the video clip than in 2D, where interaction with the interface does not take place (cf. Fig. 12).

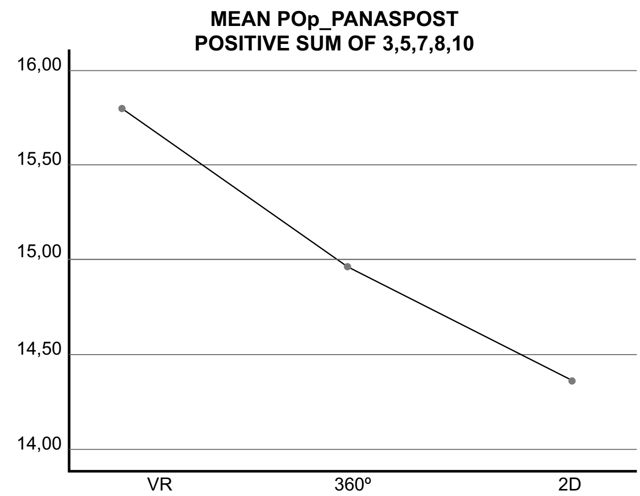


**Fig. 13** Positive effects in the post-test (POp)

A final analysis corresponds to the measurement of the possible influence of the interface on the change of affective state between pre-test and post-test, before the interaction with the video clip (PANASB) and after (PANASA). The results for the different PANAS indicators (see Figs. 13, 14, 15, 16, 17 and 18), indicate that there are differences between the three experimental groups. While VR induces higher positive effects than 360º and 2D after interacting with the video clip (Fig. 13), 360º induces a higher rate of negative effects in post-test (Fig. 14). In the set of the affective balances of the post-test (POB), that is to say, of the sum of the positive affections minus the negative ones, the VR induces a greater degree of positive affections than the 360º and the 2D (Fig. 15).

A complementary analysis, which shows the differences between the groups, is given by the comparison in the affective balance between the PRB of the pre-test and the POB of the post-test. The PRB indicator is the balance of positive affects minus negative ones in the pre-test. The POB indicator is the same balance, but in the post test (cf. Fig. 15). The comparison between PRB and POB, that is, the affective state before and after the video clip, shows that in VR there is a significant improvement after the experience (PRB:

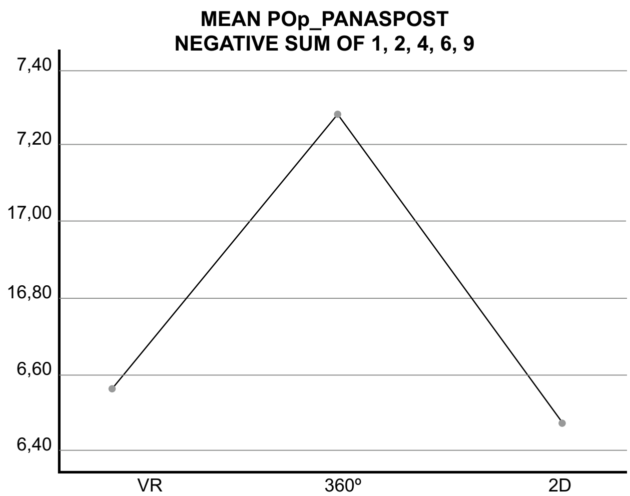


**Fig. 14** Negative effects in the post-test (POn)

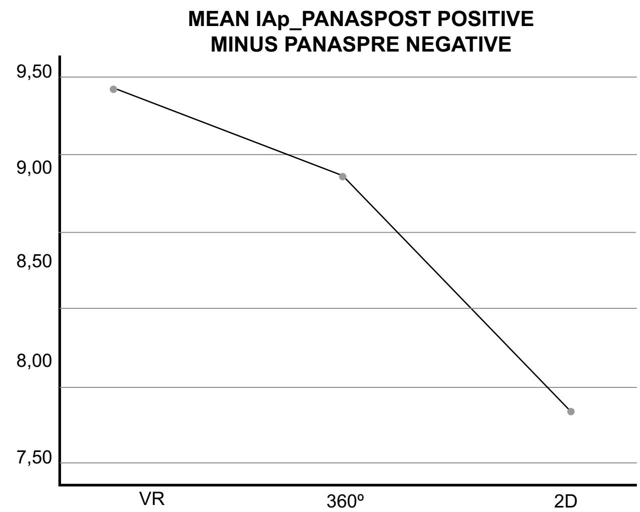


**Fig. 16** Post-test positive affect balance less positive affect in pre-test (IAp)

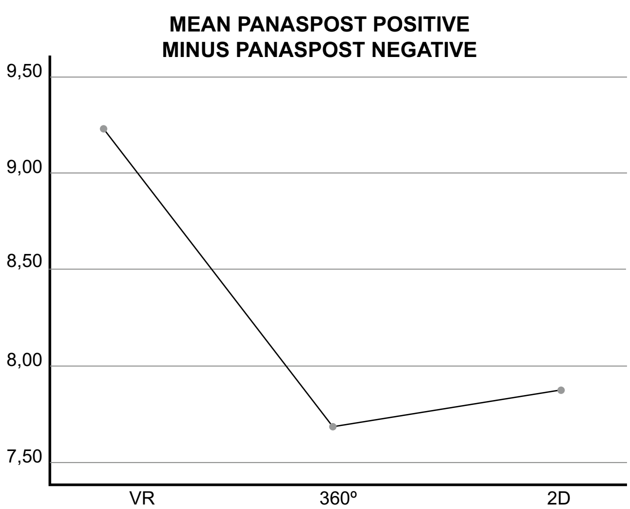


**Fig. 15** Post-test affective balance (positive affects minus negative affects) (POB)

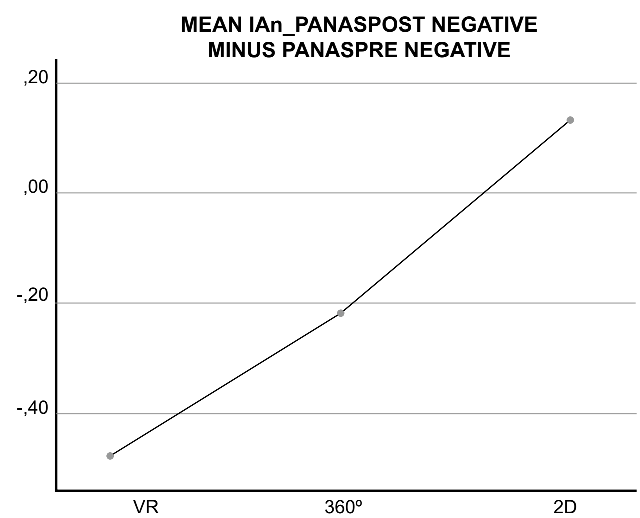


**Fig. 17** Negative affect balance in post-test less negative affect in pre-test (IAn)

M = 7.17; SD = 3.02; POB: M = 9.23; SD = 3.82). This 2.05 point improvement is statistically significant [$(t(53) = -5.47$, $p < 0.001$]. In contrast, in both 360º and 2D there is no such improvement nor is it statistically significant (360º: ($t(46) = -2.81$, $p = 0.008$; 2D: $t(44) = -1.01$ $p = 0.317$).

On the other hand, it has been analysed separately if between the pre-test and the post-test the positive and negative affects increase or decrease. The IAp index is the positive balance at the end of the test (positive affects in the post-test minus positive ones in the pre-test). The results show that this index increases more in VR than in the other groups (cf. Fig. 16). On the other hand, the negative balance (IAn index), which results from subtracting the negative effects of the pre-test from those of the post-test, increases by 360º and above all by 2D (cf. Fig. 17). All these analyses are reflected in the General Balance of Affects or IAG (post-test balance POB minus pre-test balance PRB). There is a total balance of positive effects more favourable to VR, less than 360º and hardly existing in 2D (cf. Fig. 18). Therefore, VR induces a better positive affective balance than the other groups.

In short, based on the indicators we have just presented, VR induces a greater degree of entertainment and 360º a greater cortical activation (arousal), even though it must be taken into account that many participants are interacting with these interfaces for the first time. The 2D is the least entertaining. Therefore, we see that hypothesis H1 is fulfilled. The same content induces a different spatial

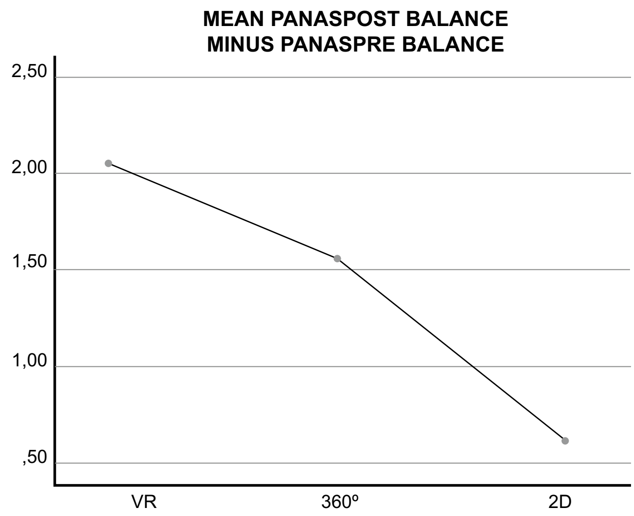


**Fig. 18** General balance of affects: post-test balance minus pre-test balance (IAG)

exploration, presence and entertainment according to the type of interface used. The question that arises now is to know the relationships between these three dimensions.

## 5.2 The relationship between virtual space exploration, presence, and entertainment

Firstly, we have analysed whether there is a relationship between exploring virtual space (EXES) and the perception of presence (PRE). Two types of results appear. First, the possible relationship between total spatial exploration, that is, the sum of the participant's exploration in all quadrants (EXET), and the degree of presence (PRE) has been analysed. The simple regression line shows that there is no relationship between space exploration and presence (PRESENCE-SPES: $R^2 = 0.012$;$F$ (1,107) = 1.341; $p = 0.249$; $B$ -0.08 *SEB* 0.07; scale SPES-SLT: $R^2 = 0.002$;$F$ (1,107) = 0.214; $p = 0.645$; $B$ −0.03 *SEB* 0.07; Scale SPES-PAT: $R^2 = 0.028$; $F$ (1,107) = 3.076; $p = 0.082$; $B$ −0.13 *SEB* 0.07;). It has also been investigated whether there is a relationship between spatial exploration and presence, depending on whether EXES spatial exploration is low, medium or high. Pearson's chi-square shows that there is also no relationship with the presence (PRE-SPES: $\chi^2$ (4, $N = 109$) = 2.31, $p < 0.05$ (sig. 0.679); scale SPES-SLT: $\chi^2$(4, $N = 109$) = 3.22, $p <$ 0,05 (sig. 0.521); Scale SPES-PAT $\chi^2$(4, $N = 109$) = 0.34, $p < 0.05$ (sig. 0.987). This is true even when spatial exploration is high (34–59 quadrants) ((EXETHigh: $R^2 = 0.04$; $F$(1, 32) = 1.396; $p = 0.246$; $B$ −0.26 *SEB* 0.22).

On the other hand, this surprising result has led us to deepen the relationship between space and presence. We have proceeded to a disaggregated analysis of total spatial exploration. The degree of exploration of the frontal, right and left space does not influence the degree of presence experienced, but the back quadrant does, under certain conditions. When the rear scan is low or medium there is no relationship with presence. However, when scanning was high (34–59 quadrants) and includes scanning of the rear quadrant, if there is a relationship between space and presence (EXETbackHigh: $R^2 = 0.07$; $F$ (1, 140) = 10.279; $p = 0.002$; $B$ 4.24 *SEB* 1.32).

Therefore, in relation to the H2 hypothesis, there is only a relationship between exploring the virtual space and the degree of presence, when the exploration is high and includes the back quadrant. This is a more exhaustive exploration of omnidirectional space.

Secondly, we have investigated whether there is a relationship between spatial exploration and achieving greater levels of entertainment. The results of different statistical tests (correlation, MANOVA) show that greater exploration of virtual space does not mean greater entertainment (thus not confirming H3). There is also no relationship between exploring the back space and the entertainment experienced.

Thirdly, the analysis of the relationships between Presence and Entertainment shows that significant relationships exist. As shown in Table 1, Presence correlates with all the Entertainment variables. The more Presence, the more Entertainment. On the other hand, the variable Arousal (AROU) has a significant but inverse correlation with Presence (PRE): the greater the arousal, the lesser the presence. This shows, as we saw above, that the Arousal (AROU) is a variable that contributes a different meaning to the remaining entertainment variables.

On the other hand, Tables 2, 3 and 4 also shows that even though in the VR group the correlation is higher than in the 360º and 2D groups, the correlation between PRE and ENT is present in all three groups.

Also, as Table 5 shows, the predictors are statistically significant. Therefore, we can accept the hypothesis (H4) that Presence and Entertainment are related. The greater the presence, the greater the entertainment.

## 5.3 The influence of previous personal experience in VR, 360º and interactive media on the spatial exploration, entertainment, and presence

In relation to the H5 hypothesis, we have carried out three sets of analyses.

Firstly, we have investigated the possible influence of previous experience with VR, 360º and/or interactive digital entertainment such as video games on the exploration of virtual space. The subjects' experience with VR is very small. Of total 147 participants, almost half had no experience with VR (46.3%); some had used an HMD once (35.4%); 15.6% many times; and 2.7% had one but used it very little.

**Table 1** Correlations between Presence perception and Entertainment variables (AROU, AFRE, ATV, ATMUA, IAp, IAG) ($N = 147$)

| PRE*ENT | AROU | AFRE | ATV | ATMUA | IAp | IAG |
|---|---|---|---|---|---|---|
| PRE | −0.214** | 0.445** | 0.483** | 0.309** | 0.374** | 0.372** |
| | 0.009 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| AROU | | −0.376** | −0.344** | −0.259** | −0.227** | −0.224** |
| | | 0.000 | 0.000 | 0.002 | 0.006 | 0.006 |
| AFRE | | | 0.673** | 0.557** | 0.461** | 0.460** |
| | | | 0.000 | 0.000 | 0.000 | 0.000 |
| ATV | | | | 0.522** | 0.405** | 0.416** |
| | | | | 0.000 | 0.000 | 0.000 |
| ATMUA | | | | | 0.389** | 0.481** |
| | | | | | 0.000 | 0.000 |
| IAp | | | | | | 0.831** |
| | | | | | | 0.000 |

G**. The correlation is significant at the 0.01 level (bilateral)

$p < 0.05$*; $p < 0.01$** Pearson correlation Sig. (bilateral)

**Table 2** Correlations between Presence perception and Entertainment variables (AROU, AFRE, ATV, ATMUA, IAp, IAG) in the VR group ($n = 54$)

| PRE*ENT | AROU | AFRE | ATV | ATMUA | IAp | IAG |
|---|---|---|---|---|---|---|
| PRE | −0.220* | 0.505** | 0.396** | 0.327** | 0.368** | 0.345** |
| | 0.045 | 0.000 | 0.000 | 0.002 | 0.001 | 0.001 |
| AROU | | −0.259* | −0.336** | −0.333** | −0.214 | −0.203 |
| | | 0.018 | 0.002 | 0.002 | 0.050 | 0.065 |
| AFRE | | | 0.639** | 0.541** | 0.404** | 0.429** |
| | | | 0.000 | 0.000 | 0.000 | 0.000 |
| ATV | | | | 0.475** | 0.336** | 0.348** |
| | | | | 0.000 | 0.002 | 0.001 |
| ATMUA | | | | | 0.374** | 0.442** |
| | | | | | 0.000 | 0.000 |
| IAp | | | | | | 0.836** |
| | | | | | | 0.000 |

$p < 0.05$*; $p < 0.01$** Pearson correlation Sig. (bilateral)

**Table 3** Correlations between perception of Presence and Entertainment variables (AROU, AFRE, ATV, ATMUA, IAp, IAG) in the 360° group ($n = 47$)

| PRE*ENT | AROU | AFRE | ATV | ATMUA | IAp | IAG |
|---|---|---|---|---|---|---|
| PRE | -0.223 | 0.211 | 0.476** | 0.227 | 0.189 | 0.373* |
| | 0.221 | 0.246 | 0.006 | 0.212 | 0.301 | 0.036 |
| AROU | | −0.488** | −0.460** | 0.008 | −0.435* | −0.301 |
| | | 0.005 | 0.008 | 0.965 | 0.013 | 0.094 |
| AFRE | | | 0.578** | 0.443* | 0.602** | 0.398* |
| | | | 0.001 | 0.011 | 0..000 | 0.024 |
| ATV | | | | 0.531** | 0.465** | 0.437* |
| | | | | 0.002 | 0.007 | 0.012 |
| ATMUA | | | | | 0.415* | 0.520** |
| | | | | | 0.018 | 0.002 |
| IAp | | | | | | 0.824** |
| | | | | | | 0.000 |

$p < 0.05$*; $p < 0.01$** Pearson correlation Sig. (bilateral)

**Table 4** Correlations between perception of Presence and Entertainment variables (AROU, AFRE, ATV, ATMUA, IAp, IAG) in group 2D ($n=45$)

| PRE*ENT | AROU | AFRE | ATV | ATMUA | IAp | IAG |
|---|---|---|---|---|---|---|
| PRE | 0.031 | 0.301 | 0.457** | 0.161 | 0.534** | 0.317 |
| | 0.868 | 0.100 | 0.010 | 0.387 | 0.002 | 0.082 |
| AROU | | −0.447* | −0.277 | −0.309 | −0.149 | −0.243 |
| | | 0.012 | 0.131 | 0.090 | 0.425 | 0.187 |
| AFRE | | | 0.849** | 0.727** | 0.502** | 0.584** |
| | | | 0.000 | 0.000 | 0.004 | 0.001 |
| ATV | | | | 0.574** | 0.490** | 0.477** |
| | | | | 0.001 | 0.005 | 0.007 |
| ATMUA | | | | | 0.369* | 0.491** |
| | | | | | 0.041 | 0.005 |
| IAp | | | | | | 0.825** |
| | | | | | | 0.000 |

$p<0.05$*; $p<0.01$** Correlación de Pearson Sig. (bilateral)

**Table 5** Linear regression of the PRE predictor on the Entertainment variables

| | $R^2$ | *F* | *B* | SE B | *β* | *t* | *p* | *M* (mean) | *DT* (Dev.) |
|---|---|---|---|---|---|---|---|---|---|
| Model (AFRE) | 0.198 | 35.859 (1,145) | | | | | 0.000 | 5.66 | 1.17 |
| Constant | | | 4.107 | 0.273 | | 15.043 | 0.000 | | |
| Predictor (PRE) | | | 0.052 | 0.009 | 0.445 | 5.988 | 0.000 | 29.88 | 10.02 |
| Model (AROU) | 0.046 | 6.950 (1,145) | | | | | 0.009 | 2.97 | 0.93 |
| Constant | | | 3.564 | 0.237 | | 15.019 | 0.000 | | |
| Predictor (PRE) | | | −0.020 | 0.008 | −0.214 | −2.636 | 0.009 | 29.88 | 10.02 |
| Model (ATMUA) | 0.095 | 15.264 (1,145) | | | | | 0.000 | 5.29 | 1.15 |
| Constant | | | 4.237 | 0.285 | | 14.877 | 0.000 | | |
| Predictor (PRE) | | | 0.035 | 0.009 | 0.309 | 3.907 | 0.000 | 29.88 | 10.02 |
| Model (ATV) | 0.233 | 44.069 (1,145) | | | | | 0.000 | 4.00 | 0.72 |
| Constant | | | 2.961 | 0.165 | | 17.950 | 0.000 | | |
| Predictor (PRE) | | | 0.035 | 0.005 | 0.483 | 6.638 | 0.000 | | |
| Model (IAp PANAS) | 0.140 | 23.528 (1,145) | | | | | 0.000 | 1.35 | 2.88 |
| Constant | | | −1.861 | 0.697 | | −2.668 | 0.008 | | |
| Predictor (PRE) | | | 0.107 | 0.022 | 0.374 | 4.851 | 0.000 | 29.88 | 10.02 |
| Model (IAG PANAS) | 0.138 | 23.268 (1,145) | | | | | 0.000 | 1.64 | 3.38 |
| Constant | | | −2.104 | 0.818 | | −2.571 | 0.011 | | |
| Predictor (PRE) | | | 0.125 | 0.026 | 0.372 | 4.824 | 0.000 | | |

$p<0.05$

In total, this no or very little experience with VR for most subjects is similar in all three experimental groups and in the ANOVA there are no significant differences between them ($F(2,146)1.97$, $p=0.143$). The previous experience with the 360º video is greater, even though 26.5% had never experienced it before (34.7% once; 34% from time to time; 4.8% many times). However, this increase in previous experience with the 360º has an influence on the exploration of space during the present experience. The almost zero previous experience with VR allows us to understand that simple linear regression shows that there is no statistically significant relationship between previous experience with VR (EXPVR) and the exploration of virtual space (EXPVR y EXET: $R^2=0.00$; $F$ (1,107) = 0.00; $p=0.997$; $B$ −0.005 *SEB* 1.48). However, there is a relationship between the previous 360º experience and the exploration of virtual space (EXP360º y EXET: $R^2=0.83$; $F$ (1,107) = 19.652; $p=0.001$; $B$ 4.11 *SEB* 1.32). In the case of the 360º, there is previous experience with the more extensive interface. This positive statistical relationship would show the influence of the previous experience with the interface in the way of exploring the space in the present research.

We have investigated a second variable (GAMER) that provides us information about the influence of previous experience in digital interactivity on the exploration of virtual space. Information has been collected on the time spent playing video games (GAMER1), frequency of time spent on video games (GAMER2), current time spent on video games (GAMER3), favourite genres (GAMER4) and video games currently played (GAMER5). It has been analysed if there is a relationship between that previous interactive experience with video games and different variables of the exploration of the virtual space. Among these variables, of interest is the interactive activity currently carried out by the participant (GAMER5). Table 6 shows the correlations of this variable GAMER5 with different spatial exploration variables during the present investigation. We can see that there is no correlation between GAMER and EXES-Total, that is to say, at a global level it is not the quantitative total of the number of spatial explorations carried out that is significant but rather the quality as we shall see below. As Table 6 shows, there are positive correlations between the subject's current interactive activity with the left quadrant scan and especially in the back quadrant (EXES-Left, EXES-Back). In contrast, exploring the front and right quadrant is not significant. Medium and especially high spatial exploration has significant correlations with the subject's experience with video games (EXES-Back/medium/high/medium and high/comp). This result goes in the same direction as what we had found above in analysing spatial exploration (EXES). Previous experience in digital interactivity would encourage a more thorough and intentional exploration of the omnidirectional space, as it also includes the left and back quadrants. It can be said that it is a more qualitative exploration as this greater exploration makes the content of the video clip more accessible.

Secondly, it has been analysed whether the previous experience of interactivity in virtual spaces influences the degree of entertainment experienced with the video clip. Multiple regression analyses of previous experience variables (EXPVR, EXP360, GAMER1, GAMER2, GAMER3, GAMER4, GAMER5) on entertainment variables (AROU, AFRE, ATV, ATMUA, AIp, IAG) have been performed. The result is that none of the analyses performed return statistically significant relationships. Therefore, it cannot be said that there are relationships between previous experience and current entertainment.

Finally, it has also been analysed whether there is a relationship between previous experience and presence. The results of the multiple regression analysis of the same set of variables on presence show that there is also no statistically significant relationship between previous experience and presence.

**Table 6** Correlations between the participant's current interactive activity and the exploration of virtual space (GAMER5 EXES)

| | EXES Total | EXES Left | EXES Front | EXES Right | EXES Back | EXES Subgroups | EXES Back medium | EXES Back high | EXES back medium and high | EXES back comp |
|---|---|---|---|---|---|---|---|---|---|---|
| GAMER5 | 0,285 | 0.359* | 0,158 | 0,197 | 0.288* | 0,277 | 0.352* | 0,437** | 0.395** | 0.319* |
| | 0.052 | 0.013 | 0.289 | 0.184 | 0.049 | 0.059 | 0.015 | 0.003 | 0.006 | 0.029 |

Correlación de Pearson (Sig. bilateral) (gl. 146 $p < 0.05$)

### 5.4 Interface preferences and interactivity in VR and 360° after participation in the experience

At the end of the second session, all participants in the three groups were able to interact with the experimental video clip with the interface they had not used in the first session within their experimental group. In this way, all of them have been able to experience interactivity with the same content in both VR and 360º. This has allowed them to make an opinion of each one of them and therefore to fill in the scales and questionnaires that we have asked them for. The variables in which this information is included are COMP, INTER, PAP, FRUS. In this way, the possible influence of the experience and evaluation of the interactivity with the virtual space experienced after the participation in the research has been analysed.

In a first analysis, it has been investigated which of the two interfaces is preferred in this experience. 79.5% of all subjects ($n = 122$) preferred the VR experience while 21.8% preferred the 360º. When asked why they preferred one or the other interface ($n = 121$), 70.2% preferred VR because it was more immersive, 12.4% preferred VR because it was more innovative, 12.4% preferred 360º because it was more comfortable and 5% also preferred 360º because it was of higher quality (in this particular experience). The analysis of variance shows that these perceptions do not differ from the group in which the subject has been in the experience (F(3,120)2,59, p = 0.056). It should be noted in this comparison that the high percentage of subjects who prefer VR (82.6%) could be even higher since some subjects, out of the 12.40% who choose 360º, do so because VR causes them some kind of physical inconvenience (problems with their glasses, vertigo or dizziness, …), while, for them, 360º does not present these inconveniences and they therefore consider it more comfortable.

In a second analysis, the participants' assessment of their interactive experience with the interface (INTER scale) was investigated. The analysis of variance indicates that there are no differences between the groups, so their assessments are not consistent with the group in which they were initially located. (INTER-360º: $F$(12,121)1.28, $p = 0.237$; INTER-VR: $F$(12,121)0.54, $p = 0.869$). This 5-point INTER scale includes three items. The first, the $T$-test of related samples indicates that there are significant differences. Subjects report greater ease of interaction with VR than with 360º (VR: $M = 4.18$; $SD = 0.88$; 360º: $M = 3.47$; $SD = 1.20$; $t(121) = 5.41$, $p < 0.001$). The second item, the $T$-test of related samples indicates that there are also differences and the participants report having a greater degree of freedom to move within the video clip in VR than in 360º (VR: $M = 4.03$; $SD = 0.09$; 360º: $M = 3.63$; $SD = 1.18$; $t(121) = 2.93$, $p = 0.004$). In the third item, we also found differences in favour of VR. Participants have a perception of being more comfortable with the use of the interface and VR than with 360º. (VR: $M = 3.85$; $SD = 1.09$; 360º: $M = 3.33$; $SD = 1.29$; $t(121) = 3.29$, $p = 0.001$).

A third analysis has investigated the perception of feeling able to interact with the video clip (PAP scale). On a 5-point scale, subjects attributed a mean of 4.03 (SD = 0.89) to their ability to interact with the VR and a mean of 3.44 (SD = 1.09) on the 360º. The T test of paired samples shows that these differences are significant ($t(121) = 4.71$, $p < 0.001$). We see that, even though a significant percentage of participants consider that they can interact adequately with the interface, the opinion is again more favourable for VR.

Finally, a third scale (RUF) collected the participant's perception of the degree of frustration they had experienced because of the interface used in the first session (HMD or keyboard). On a five-point scale, the average degree of frustration in VR is 2.07 (SD = 1.05) and in 360º 2.54 (SD = 1.18). The T test of paired samples shows that these differences are significant ($t(121) = -3.40$, $p = 0.001$). Therefore, there is more frustration in interacting with 360º than with VR.

In summary, the VR experience is preferred to the 360° experience, there is a perception of better interaction and movement with VR, and finally, there is less frustration when interacting with VR. This confirms the H6 hypothesis.

## 6 Discussions and conclusions

The results of this research allow us to advance in our knowledge of the relationships between the exploration of virtual space, presence, and entertainment. As Fuchs (2017) points out, the purpose of virtual reality is to make possible a sensorimotor and cognitive activity for a person (or persons) in a digitally created artificial world. Until now, it was considered that the more space exploration, the more presence, and entertainment. However, things are more complex, as this research shows.

Spatial exploration is a necessary but not enough condition to achieve perception of presence and entertainment. The results show that sensorimotor activity, which leads to the exploration of virtual space, can be of two types. A first type, which we will call interface dependent, is characterized because the user makes a saccadic exploration of the virtual space. When the user begins to contact the interface, starts a phase of discovery of the intermediary device. Their motor and sensorimotor behaviour can be febrile. They are not so much interested in the content as in exploring the possibilities offered using an unfamiliar device that allows them to find themselves immersed in a virtual universe that is new to them. Although their motor and sensorimotor movements are abundant, they do not, paradoxically, make an exhaustive exploration of spherical space. It can be said that at least part of the user's attention is directed to using the interface, to becoming familiar with it. This type of sensory-motor activity is especially present in users who are not very familiar with interactive and VR devices.

A second type of exploration of virtual space, quite different from the previous one, is the independent or exploratory interface. The user has greater familiarity and experience with interactive devices (e.g., video games). Their exploration of virtual space is not saccadic but is more related to voluntary exploration and discovery of spherical space and its content. Although they can perform a high exploration of space, this interest in content can lead them to perform fewer motor movements, compared to the user-dependent interface, but more select, precise and exhaustive of virtual space. The last one is manifested in that it includes in its exploration the back quadrant guided by that desire of appropriating the content. Secondly, the differences between these two types of users are also shown in the psychological effects that these styles of exploration of virtual space induce. The user interface dependent has a lower perception of presence than the user interface independent. Also, the degree of entertainment of the first one is lower.

In conclusion, the perception of presence and entertainment in virtual reality does not depend so much on the amount of interactive behaviour but on the quality of that interaction. The interface, when it is not mastered due to lack of experience, is a brake on the entertainment experience. On the contrary, when enough skill has been acquired in its use, it becomes an ally of the user in his interaction with the virtual universe. This raises the necessary learning processes of interactive devices as previous steps to the enjoyment experience. These same processes can be observed in other fields, such as learning to drive a car. In the field of VR, it is very important to consider this factor as it has very important applied repercussions (for example, in medicine or flight simulation).

Secondly, in relation to the discussion raised, from the conception of the two-level model of the formation of spatial presence by Wirth et al. (2007) and Hartmann et al. (2016), about the factors that contribute to its formation, the results of this research indicate that the perception of presence is influenced by the type of spatial exploration. When it is guided by the content, the interface takes a back seat (independent interface), because it is simply a tool at the service of interactivity with the content. In this type of spatial exploration, as we have just seen, the perception of presence is greater than when spatial exploration is saccadic and random. In this way, spatial exploration and presence are related. In turn, a greater cognitive activation of presence perception corresponds to a greater degree of experienced entertainment. Therefore, presence and entertainment are also related.

Thirdly, entertainment is greater in VR than in 360º (or 2D) because the user can explore the content of the virtual world as a result of the sensory stimulation and sensorimotor activity of the interface that allows greater presence in the virtual world compared to 360º. The way of interacting with that virtual world through the interface is a factor that influences the enjoyment. When spatial exploration is saccadic, interface dependent, there is no entertainment. Just arousal that does not translate into pleasure. Instead, interface independent, content-driven spatial exploration induces entertainment. This means that the way the user explores virtual space is a factor in the VR enjoyment experience. Just as greater presence is also accompanied by greater enjoyment.

In conclusion, this research provides a typology of virtual space exploration that highlights the links and intimate relationships between interactive virtual space exploration, presence and entertainment, three key features of interactive devices in general, and those of VR.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s10055-021-00510-9.

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