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360° versus 3D Environments in VR Headsets for an Exploration Task

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Abstract

For entertainment, pedagogical or cultural purposes, there is a need for fast and easy setup of virtual environments that represent real ones. The use of 360° video in Virtual Reality Headsets seems like a powerful tool for producing fun and engaging content in a fast manner. This applies even more when we need to set up realistic views of actual environments.
However, in terms of user experience in virtual reality headsets, can 360° shots of a real environment be an interesting alternative to a full 3D model?
In this work, we have conducted a user study during a film festival comparing the reaction of a wide public to two versions of a Virtual Reality cultural heritage visit of a Paleolithic cave, the "Grotte de Commarque" located in the south of France. The first version is a full 3D textured model of the cave, the second is a series of 360° pictures, presented in a VR Headset. We have set up a scenario of observation and exploration. The users were able to navigate with the same teleportation metaphor in both conditions. We focused on evaluating the sense of presence during the visit. We have also sought for trends in perceived fun, sickness and easiness of navigation. Our results suggest that the full 3D environment is where the participants feel more present. However, the difference in rating the measures between the two conditions were not strongly marked. Moreover, a relevant result that we retain is that this rating is correlated to the degree of familiarity of the user with virtual reality.

CCS Concepts
•***Human-centered computing*** → ***Virtual reality;***

1. Introduction

360° content builds up massively on video sharing platforms, and these platforms allow to use a virtual reality headset to explore it. Due to the nature of the data, interactivity in such environments is reduced compared to classic virtual reality environments where 3D representation of objects allows to change aspects of the scene, or manipulate objects.
Nevertheless, 360° could provide an easy way to set up immersive experiences, at least for the ones that only require visual observation and no active modification of the environment. This can be a large real scenery for exploration of a natural landscape, a power plant for a gamified learning environment, or an inaccessible cultural landmark for a VR visit by the wide public.
To start simply, we will not focus on complex interaction (object manipulation) in 360° content in this work. As a first step, we want just to consider how user experience changes if we replace a 3D environment with a grid of 360° shots in which the user can switch viewpoints creating an illusion of moving around, without considering manipulation of objects. Indeed, to the best of our knowledge, this simple but primordial question is not treated in the literature.
In this paper, we chose to tackle this question by comparing an observation task in a 3D and 360° conditions representing the exact same environment.
Creating immersive user experiences that involve representations of real sceneries or environments require the creation of visual data. Creating 3D models of real environments is a long and costly process. We can consider two main approaches:

1. Artistic approaches where objective correspondence of the model, in terms of geometry and colors, is not a primary goal.
2. Objective measures with specific apparatus that aim at being as closer as possible to the ground truth.

In the first case, the artist reproduces what he sees in a modeling software. He can eventually use pictures of the real environment as sources for texturing the 3D model. In the second case, specific 3D data acquisition and object reconstruction techniques are used, such as Photogrammetry, Lasergrammetry, Time-of-fiight cameras or Structured light 3D scanners. Both artistic approaches and objective measurement techniques are potentially time consuming and costly.
By contrast, 360° video acquisition can be faster and easier to setup. A single 360° texture can be obtained in a few seconds thanks to commercially available cameras, by simply placing the camera and shooting (remotely if presence of persons is not de-

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sired). Besides, 360° videos seem to bring some other advantages. For example, it allows to easily add actors in the scene, by using real ones. Whereas in 3D content, adding real or virtual actors can require a lot of work as avatars are prone to the problem of uncanny valley [Mor70].
Thus, the use of 360°cameras is tempting, but if we consider the user experience point of view, are there differences with using a 3D content? To tackle this question, we propose to compare a 360° based vs a 3D model based exploration method in the use case of a VR cultural and touristic visit. Since the proposed task is exploration, we need to allow the user to see different parts of the cave. In the case of a 3D model, this is easily done with a navigation metaphor that moves a virtual camera around. In the case of 360° data, a single point of view is not enough to cover the whole cave as it comprises several hidden parts and a corridor. In order to answer that need, we chose to have a visual coverage of the cave with several 360° points of view (POV). Actually, this coverage is done by a series of regularly spaced POVs, creating a virtual grid of POVs within the cave. So the common point between the two methods of exploration is a virtual grid of waypoints in the scene. In the 360° condition, the visual information is a 360° shot seen from a given waypoint, and if she or he were able to switch to 3D content, one would see the 3D environment from the same waypoint. A navigation metaphor is provided and described in section 3.
So, we compare non stereoscopic 360° shots versus a 3D model in a VR Headset. Clearly, monoscopic 360° shots provide less depth information compared to a 3D stereoscopic environment. However, the focus of this paper is to assess to what extent the absence of stereoscopic depth cues in 360° videos affects the user experience in an exploration task.
In the following, we first present works that have compared or combined 3D and 360° content. Then we present our use case, how we have set-up the data, and the observation and navigation activity within the virtual environment. We then describe the 360° vs 3D comparative user study that was done, involving a wide public during a film festival. We discuss our results and implications for wide public use of VR for exploring virtual environments.

2. Related works on 360° and 3D content

2.1. Understanding 360° content

To our knowledge there is no work that has considered the question of comparing 360° and 3D content in user experience in exploring representations of a real environment in VR headset. Some works have considered the question of human understanding of 360° content. In the case of visuo-spatial understanding, Hernandez et al. [HG15] compared photographic-based representations of space, on a desktop setup, such as Google Street View, with a navigation in the real world. The questions raised by the authors was to determine which aspects of a real experience might be replicated in a virtual environment. In this paper a comparative analysis between the real and virtual traversing of an urban zone was conducted. Not surprisingly it was found that the sense of presence, immersion and flow is higher in the real environment experience. Their results suggest the strong role of dynamic point of view and gaze direction, and point out keyboard / mouse controls as one of the limitations.

Syrett et al. [SCvG17] have considered the understanding of the storyline of a 360° video in an Oculus Rift. The level of feeling of distraction and enjoyment were measured. The purpose of this study was to understand how the increased freedom of the point of view affects comprehension of 360° films. Their results argue that although some important factors of a storytelling may be missed due to the free point of view the general comprehension of the movie remains intact. These results suggest that VR devices offer a lot of potential for the film industry and storytelling games. The challenge will be for the director to guide the attention of the viewer.

2.2. Improving 360° content

Different strategies were developed in order to enhance user experince in 360° content.

Better Visual Rendering

Several works aim at bettering the overall visual realism of 360° content with the objective of an enhanced experience. Nie et al. seeked at increasing visual realism with better stitching algorithms of 360° videos [NJ17]. Rhee et al. proposed methods for inserting 3D objects into 360° content, and ensuring correct perspective and shadows [RPAC17], panoramic video is also used as an environment map for simulating global illumination. Their approach is called a mixed reality MR given that the real content is the video. User questionnaires show a better sense of presence with the MR features.

Adding Interaction

Allowing user interaction within the 360° content is another possibility to achieve user involvement and better experience. Argyriou et al. have proposed a framework towards this end by identifying a set of technical and design challenges for gamified video 360° that mixed 360° video and 3D computer generated objects [AEBD16]. Among these challenges, they propose time pressure challenges, badges and user levels, storytelling narrative and immediate visual feedback. Their effects are yet to be studied. The authors also proposed a branching narrative technique presenting a virtual scenario where the user has several choices within the environment to experience it in different ways. Chambel et al proposed a similar approach by integrating hyperlinks in different areas of the video allowing transitions to another environment [CCN11]. This approach can be found in games such as Heavy Rain [Qua10] where branching in the story is done by user decisions.
An other example is In Fort McMoney , where the user can select to move in the story through hotspots that are presented at the end of a 360-degree video resource on a static panoramic images or through the user interface buttons at the bottom of its screen. Pakkanen et al. in [PHJ*17] compared three different interaction methods for controlling 360° video playback. The compared methods were: remote control, pointing with head orientation, and hand gestures.

Our approach for 360° vs 3D comparison : Start with a Simple Exploration Task. Although interactivity can enhance the user experience in a 360° content, we want to focus on an exploration task that addresses more the perceptive nature of 360° versus 3D. In a way we are asking a simpler question that the role of interactions, we believe it is fundamental to start with the analysis of the role of visual data, before studying how interactions can affect user experience.

3. Virtual Visit in the Cave

Our context is the Visit of the Commarque cave [DDC*81] that was discovered in 1915. It contains invaluable parietal artworks that are estimated to have been crafted between 10 000 and 17 000 BP2 (Figure 1).

Figure 1: *Engraving of a horse In the cave of Commarque*

The paintings and sculpting are fragile and having a lot of people come in and out puts the heritage at risk of degradation. In this context the cultural actors (owners of Caves, Museum curators) see Virtual Reality as a great way to get kids and grown-ups to visit such caves and understand human (prehistory) through fun and pedagogical content. Professionals (Prehistorian, anthropologists) could also visit the cave and take time to observe from new viewpoints and seek new details without the constraints of the real cave.

3.1. Observation and Navigation in the Cave

We have set up a scenario of observation and exploration. For the observation, the setup is straightforward as the VR Headset*(HTC Vive)* we used, natively employ head movements for gaze orientation.

For the exploration of the cave, as the real one is large enough to allow movements in different directions including a hidden corridor that the visitor can walk into, a navigation method in VR was required. We have chosen to allow navigation between predefined waypoints in the cave, that the user would reach by clicking on it, thanks to the 6dof controller and a wand metaphor.
The waypoints are located on the floor of the 3D model of the cave, and stay at the same 3D location for the 360° condition. Once a waypoint is clicked over, the user is teleported at that location. We chose the teleportation metaphor in order to avoid cinetosis. Our choice of the teleportation metaphor was also motivated by our

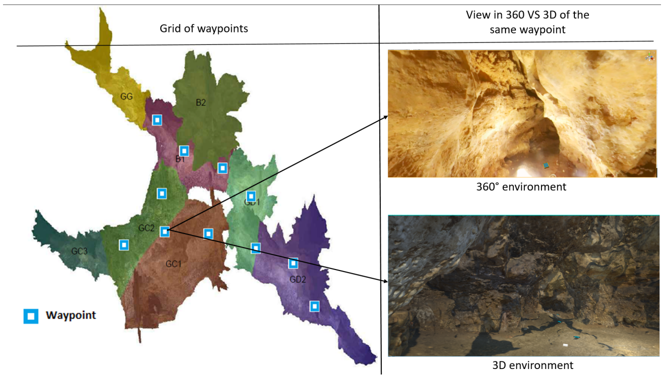

Figure 2: *Navigation through waypoints within the virtual cave.*

need to ensure equivalent navigation conditions under both conditions. The waypoints in the 3D model correspond to the 360° camera point of view (Figure 2).

3.2. Visual Data Setup

3D model generation. A 3D acquisition of the Commarque cave was done by a company using 3D scanners and cameras for textures. The result is a 300K triangles model, with a series of high resolution pictures that was UV mapped on the model by hand.

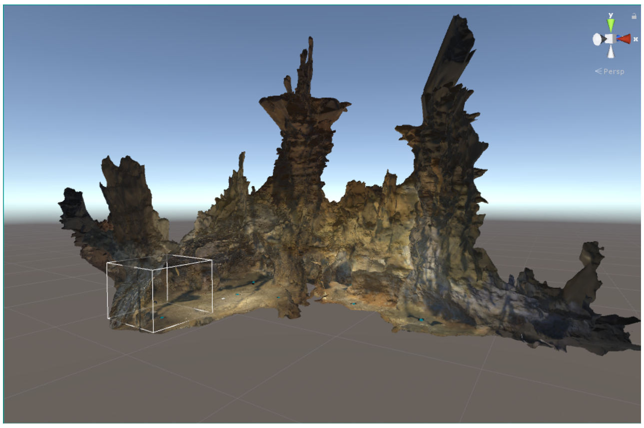

Figure 3: *3D model of the cave*

360° Data generation. As for the 360° dataset, we have used a 360° camera *(Samsung Gear 360°)*.

In order to allow different points of view in the cave, we have taken a series of 360° pictures that exactly correspond to the waypoints previously defined. The location of the camera was 1,7m above each predefined waypoint. Using the same interaction method as for the 3D model, each user was able to point and click on a waypoint and see his point of view "teleported" at the new location. The waypoints were visually presented with the same 3D objects as in the 3D dataset. For each waypoint, the user's point of

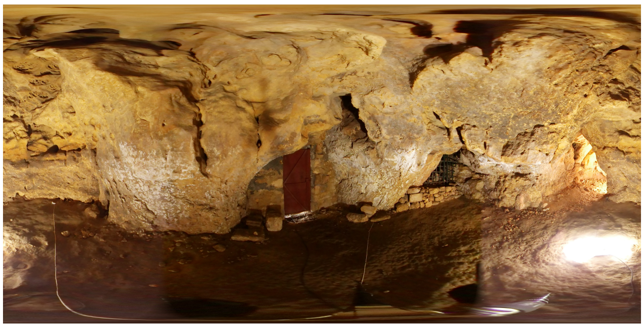

Figure 4: *360° shot of the cave*

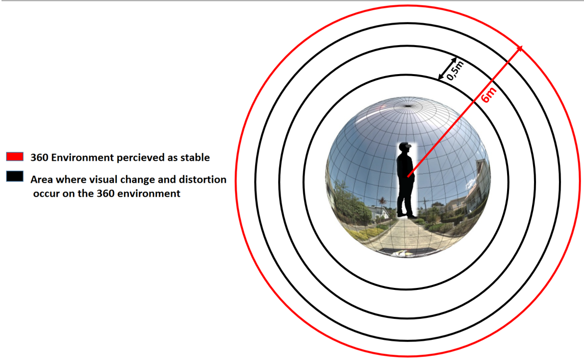

Figure 5: *Empirical study to define the sphere size*

view is instantly displaced at the center of a sphere, on which the 360 texture is mapped.

Defining the size of the Projection sphere. When we had to build up the 360° environment, the choice of the size of the sphere receiving the 360° texture appeared as an open question at the setup phase. During informal tests we have given to the users control over the size of the sphere and asked them to give their impressions. They reported that when they were changing the size in a small size range (1m to 2 m), they were able to see visual changes and distortions. Concerning variations in the large size range (4m to 6m), they reported that these changes did not occur any more. The reasons for those distortions in perception can be due to different causes. A too high parallax leading to a diplopic view in the small range is not likely to be the problem since we informally checked that we were in the range of stereoscopic fusion for the minimum size. A possible explanation is a discrepancy between monoscopic cues and stereoscopic cues for small sized spheres. Stereoscopic depth cues for small sizes of the sphere suggest a close object (the surface of the sphere itself). The monoscopic cues embedded in the textures (shadows, occultation) can suggest objects and surfaces that are further away. A second explanation that may be combined is that depth cues on the sphere are not anymore perceptible beyond a certain distance. This distortion question requires a specific study. We nevertheless conducted pretests meant to choose a visually acceptable and stable perception in the 360° condition. During these pretests, as illustrated in figure 5, we have asked 5 users to tell us when the environment appeared as not moving or being modified, while we were increasing the diameter of the sphere with 0.5 meters steps. We found a threshold of a 6 meters sphere that made people perceive a stable environment.

4. Comparing 360° vs. 3D During a Film Festival

Our perceptive study was conducted in the context of the film festival Itinerances [†].The advantage of performing the experiment out of the lab in such a venue, is that the population of participants is diversified and more representative of a general public.
In total, 23 participants were included in the study, who were aged between 13 and 63 years (mean age = 32.43 years), and they comprised 9 women and 14 men. All of the participants had normal or corrected-to-normal vision.
The participants were informed that they would perform a perceptive experiment using an HTC Vive headset. The experiment started with a general information questionnaire where they entered their age, gender and their level of familiarity with VR and gaming. In the next step, after a short tutorial to show the participants how to use the teleportation metaphor with the HTC controllers, the participants were asked to visit the representation of the cave. Starting condition (360° or 3D model) was alternated between each subject. Once the first condition finished, the participants were asked to answer a questionnaire. For the present study, we used the full IPQ Presence questionnaire(French Version[‡]) 4 items of the Simulator Sickness Questionnaire (SSQ) [KLBL93], three questions on perceived Fun, two on navigation easiness and two on the pedagogical potential of the simulation. After completing the questionnaire, each participant was invited to explore the cave again in the second condition. The same questionnaire was presented again at the end of that second phase.

Here are the Fun, Navigation, and Pedagogical related questions (illustrated in the table 1) translated from French, the participant had to grade each of them on a 0 to 7 scale corresponding to a "don't agree" to "fully agree" assessment.

The hypothesis raised by this study are:

- **H1:** Considering the supplemental depth information and the dichotomy between monoscopic 360° and stereoscopic 3D environment and adding to this the deformation in 360° condition due to the fisheye lens of the 360 camera. We assume that the sense of presence in a full 3D model will be higher rated : $Presence(3D) > Presence(360)$;
- **H2:** The navigation task will be easier in the 3D condition due to the supplementary depth information and the tracking of the headset allowing the user to move around the waypoints: $Nav(3D) > Nav(360)$

† http://www.itinerances.org/

‡ http://www.igroup.org/pq/ipq/download.php

Measures	Questions
FUN	I had fun during the virtual visit of the cave.
FUN	This virtual visit is amusing.
FUN	I would like to continue to visit this cave in the virtual environment.
LEARN	If the pedagogical content is developed, (stories, explanatory videos) this simulation can be a good pedagogical experience.
LEARN	I think i have a good mental representation of the spatial organization of the cave.
NAV	It was easy to navigate in the cave.
NAV	My movements in the cave were natural.

Table 1: *Questionnaire about Fun,learning and easiness of navigation*

5. Results

We performed a repeated measures ANOVA to test the presence, fun, learn and navigation ratings.

Presence The environment condition (3D VS 360°) had a main effect on presence rating. The ANOVA results were $F(1,44) = 20.55, p < 4e-06$. Our results suggest as shown in figure 6 that feeling of presence is higher in the 3D condition.

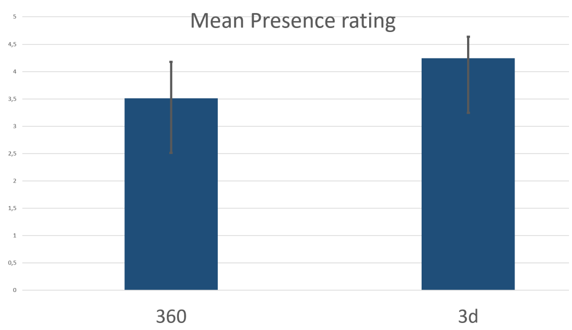

Figure 6: *Mean of Presence per condition*

Fun The environment (3D vs. 360°) had also a main effect on the perceived Fun while visiting the cave. The ANOVA results were $F(1,44) = 4.98 p = 0.03$.

3D condition was also preferred to the 360° one as shown in the figure 7.

Navigation, Sickness, Pedagogical For these questions the Anova test did not show a significant difference. However Anova about Pedagogical potential suggests a trend (p =0.06) that 3D has

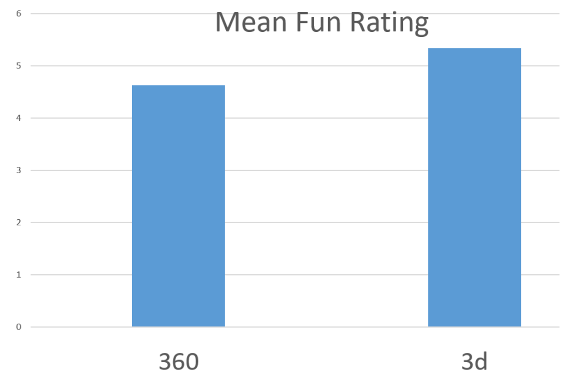

Figure 7: *Mean of Fun per condition*

more potential. More tests with a greater number of subjects are needed to confirm this.

Role of Familiarity with VR We have divided the population in three groups regarding their familiarity with VR : Low, Medium, High. We found an interaction effect between environment condition and familiarity with VR.The Anova results were $F(2,30) = 3.728 p = 0.03$. This result illustrated in figure 8 shows

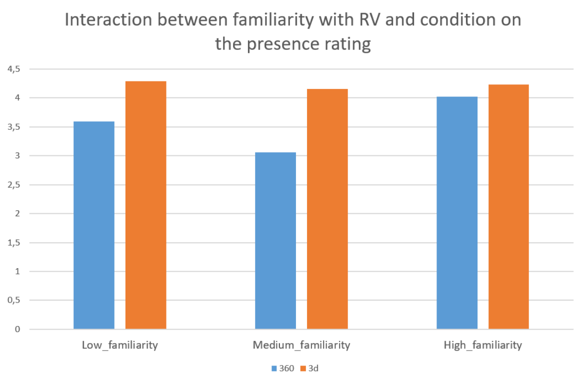

Figure 8: *Effect of familiarity with VR on the presence rating per condition*

that people with high familiarity with VR are less prone to experience a strong difference in presence between 3D and 360° content. Whereas the low and medium familiarity population, clearly perceives a stronger difference in presence.

6. Discussion

We first discuss the results on the question about the presence variable (Hypothesis H1). For one part of the population, the group that is not familiar with VR, 3D content clearly provides a better sense of presence. This result can be due to the strong difference in depth perception provided by the two environments.

A fundamental difference : depth perception A difference between the two environments is the nature of depth information provided to the user. We explain more in detail these differences in the next two paragraphs:

Binocular Information In the case of 360° textures, no binocular depth information is available as the images on each eye is produced on the basis of a pair of cameras that observe the interior of the sphere that receives the 360° texture. In the 360° case the perception of depth can only rely on monocular depth cues (shadows, occultation, perspective, relative size) and is therefore much less apparent.

Movement parallax the second difference for depth information is movement parallax, that is available in the case of 3D models, thanks to head tracking and camera movement. In the 360° case, since the sphere on which the environment texture is projected is always centered on the head of the user, no movement parallax can be perceived. And even if we had done so, (allow movement of the head within the sphere) the movement parallax would have revealed the non-realistic smooth surface of the sphere instead of the relief of the cave. In order to avoid this effect, we have locked sphere position on head position.

Stereoscopic 360° ? We used in our experiment a monoscopic version of the visual display in the headset. As described above, this comes from the fact that, for the 360° real photographic acquisition, we have placed the 360° camera at one point in the real cave, and acquired only one 360° image from that point of view. This image is then applied in the virtual environment on the sphere that surrounds the user, and two virtual cameras produce two new 360° images to display in front of each eye. These images do not contain any parallax stemming from the geometry of the cave itself, but only parallax from the geometry of the sphere used for rendering. There are however techniques for having 360° stereo pairs that do contain parallax from the actual scene. Recent 360° cameras claim to do so [JR16, WAW*16], and 360° films have succeeded to do so for the background static part of the view*(for example the 360° film, I, Philip, Arte Productions)*. The question of whether 360° stereo content would enhance the sensation of presence is open.

For the group that is the most familiar with VR, the difference in presence between 360° and 3D is not as important. This suggests that the simple fact of having tried VR before, makes those users insensitive to the lacks of 360° stimuli compared to 3D. This could be due to a simple learning effect on the general experience of wearing a VR headset. The hypothesis here is that people who have never tried VR before, can be disturbed by the constraints of a headset: not seeing the real environment, not seeing one's body and physical discomfort of the headset's straps and mask. People who have tried VR before may be less prone to this discomfort and could make the condition of 360° easier compared to the other group. Another hypothesis would depend on the type of stimuli the familiar with VR population was previously exposed to. If they had been mostly exposed to 360°, a learning effect could also take part in the general experience. However we did not use a sufficient precise questionnaire to assess the nature of the"VR culture" that this population has. In particular, we do not know which type of content they were exposed to, 360° or 3D or both of them?
More generally, those results suggest a habituation effect. Adaptation could operate on people's ability to convert monoscopic depth cues to estimate the relief of the environment through their previous experiences in VR. It could also operate on a very specific part of the 360° experience that is a source of discomfort. It is a feeling that was reported by some of the subjects. The feeling is summed up by a couple of short sentences that were often heard during the experiments:"my feet are not touching the ground!" or "I am hovering over the ground!" This feeling is due to the nature of the visual data and 360° camera lens distortion: the (virtual) ground is indeed at a distance from their feet because the texture representing the floor is placed on the large surrounding sphere. Thanks to their previous experiences, the familiar with VR group may have been able to ignore these distortions, they could therefore be more involved during the visits and thus increase their feeling of presence.

Navigation Trend

For the question of easiness of navigation (Hypothesis H2), no significant difference is found. Even if we cannot express a formal conclusion since the statistical tests are not significant, our results suggest an unexpected trend. The notation of the easiness of navigation between condition 360° and 3D seems equivalent. Figure 9 below shows that the users did not give much importance to the lack of depth information when evaluating the navigation task.

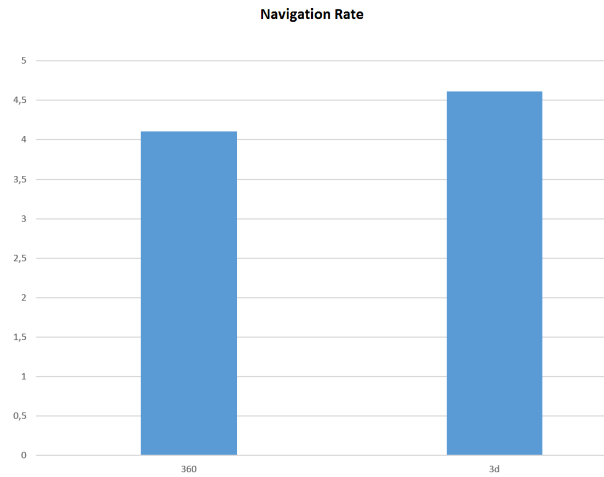

Figure 9: *Mean of easiness of navigation per condition*

Using a teleportation metaphor on a grid of 360° points of view, the displacement in a 360° environment seemed equivalent, in terms of easiness and naturalness, than a navigation in the 3D model. This trend should be studied with objective measures of navigation [NCL16, WK98] involving spatial understanding evaluations such as asking users to draw a map of the cave at the end of the experiment.

7. Conclusions

360° pictures and videos are a thriving media that has great potential. It attracts the attention of both researchers as well as professionals in video games and cinema. Yet, we have found in the

literature a real lack of user studies that compare the acceptance of this modality compared to a classic 3D environment.
Our objective in this work was to see how a navigation strategy within a spatially distributed grid of 360° shots, in which the user can switch viewpoints, hopefully creating an illusion of moving around, would compare to navigation in a 3D modelized environment.

To tackle this question, we conducted a perceptive user study that simulates an observation and navigation task in the same environment, a prehistoric cave, using the two modalities.
To this end, we had to first manage an open question that we encountered in the setup phase regarding the property of the projection sphere of the 360° shots. We conducted a preliminary empirical study to specify the size of the sphere. Our results suggest that the sphere should be positioned at a minimum radius of 6m. We hypothesize that this is, at least partly, due to the sphere surface stereoscopic depth cues that may conflict with monoscopic cues, not being visible at that distance.
Then, the subjective questionnaire results clearly suggest that 3D remains the modality that receives the most important presence and fun rates. Even though this result seems to be trivial, we found that the difference in notation was not that important. Moreover, a relevant result that we retain is that this notation is correlated to the degree of familiarity of the user with virtual reality. The more she or he was familiar with VR and wearing head mounted display the more the difference of notation between 360° and 3D was thin. However, in a future study we should consider, in our evaluation of the VR familiarity, the type of content that participants have previously experimented (360° or 3D) to be able to discuss learning and adaptation effects.
We didn't find a significant difference in the rating of navigation easiness between 360° and 3D environment and the rating for both conditions was very similar. Although, we are conscious that considering our statistical result, we can't conclude that these conditions were equivalent. It suggests that adding a waypoint navigation technique between spatially distributed 360° shots fills in some of the perceptive gaps of 360° shots.
We noticed in the related works section of this paper that there exists many attempts to improve the 360° experience whether it is technical improvements or by incorporating interactions. Those works and the study we presented in this paper suggest that 360° video has a very strong potential as VR content and could elicit acceptance and presence rates as important as 3D. Moreover, given the expansion of virtual reality devices, the general public may be increasingly familiar with VR environments. And, as our study suggests, this may result in a closer match between the two modalities immersion rates.
Using a proper combination of habituation, carefully chosen interactions, the world of entertainment, video games and cinema and domains of culture and tourism may be able, in the close future, to take advantage of the easiness of setting up 360° video without losing the sense of immersion and presence that 3D provides.
In a next step, we are planning to study the role of interaction in the visit of the cave and to compare these two modalities in a context where the user is more active. This can be done by allowing the user to manipulate 3D objects integrated to both conditions. We would also like to explore what we consider to be one of the main advantages of 360° videos: the easiness of adding actors. In different parts of the cave, there are drawings or markings that have a historical meaning and/or aesthetic value. These drawings would be an important part of the discovery for the public. To address this, we will film, in various points in the cave, a person (prehistorian, ethnologist) that would explain each painting or engraving. She or he would appear on demand by the visitor and propose, through a 360° video, an explanation. During our stay in the cave we have acquired such videos, and observed during informal tests that the presence of talking and moving persons in the 360° video have a strong effect on the feeling of presence. Avatars in 3D would be a possibility to accomplish this within the 3D version of the visit. However, those avatars may still remain less expressive and believable than a real human face in the future. Would presence be really enhanced if we populated the 360° visit with various playful characters? Again, a specific study is required to explore the question.

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