Step by Step: Evaluating the User Experience in Mixed Reality Storytelling enhanced by Motion Tracking

1st Author Name
Affiliation
City, Country
e-mail address

2nd Author Name
Affiliation
City, Country
e-mail address

3rd Author Name
Affiliation
City, Country
e-mail address

ABSTRACT

The availability of depth sensing technology in smartphones and tablets is bringing spatial awareness to the design toolbox of mobile entertainment experiences. Mixed reality (MR) is finally moving away from controlled environments, "into the wild" of urban spaces providing opportunities for seamless interactions across the continuum between the real and the virtual. In this paper we describe a storytelling MR experience and a study using different interaction techniques for navigation input. Each interaction technique allows different degrees of freedom (DOF), where increased DOF prompts physical movement. Finally, we present and discuss results from the study highlighting how the DOF enabled by the depth sensing can affect the user experience. Our findings suggest that use of motion tracking has potential to enhance user experience in terms of Presence, Immersion and Flow.

Author Keywords

Mixed Reality; Depth Sensing; Motion Tracking; User Experience

ACM Classification Keywords

H.5.1. Information interfaces and presentation (e.g., HCI): Multimedia Information Systems;

INTRODUCTION

Nowadays, physical and virtual worlds are increasingly intertwined, converging into hybrid spaces supported by networks of digital information [31]. Continuous improvements of smartphone technology are laying grounds for an emergent set of new services [3] and in particular applications that operate in these hybrid spaces through a mixed, virtual or augmented reality paradigms [36,24].

Mobile Mixed Reality (MR) experiences in fact, allow participants to inhabit both the physical and virtual environments simultaneously [14], where actions in one environment affect the presence in the other. Paul Milgram and Fumio Kishino defined a mixed reality as *"...anywhere between the extrema of the virtuality continuum*."[2], where the Virtuality Continuum, on one side has the Real Environment (RE) and on the side has a completely Virtual Environment (VE), encompassing Augmented Reality and Augmented Virtuality in between.

We position our work within the MR spectrum, as we report on the development of a MR storytelling experience, our prototype "The Old Pharmacy", containing a virtual environment of an interactive 19th century pharmacy. Most Virtual Reality (VR) experiences focuses on full immersion in the virtual world and isolation from the real world, however by positioning our experience as MR experience we whish encourage the use of real world elements in VE.

Our prototype leverages the recent adoption of mobile MR, including the availability of low cost devices enabling MR interfaces. Until very recently there was no practical and easy to use commercial off-the-self MR applications [25] but this has changed with the success of new applications and games using the combination of virtual and real world elements reaching the wider public (e.g. Pokemon GO[1], Snapchat[2]).

A recent emerging technology with potential to revolutionize the user interaction in mobile devices [19] and in particular the development of mobile MR experiences is Project Tango[3], a hybrid motion tracking device capable of supporting six degrees of freedom (DOF) enabling smart devices to have a "human-like sense of the world" around them. Through the use of depth sensing cameras and computer vision algorithms, Project Tango is able to reconstruct mathematical models of real world over time. The system estimates the movement of the device in the relation to the real world, allowing for motion tracking of the user holding the device. This "awareness" of the real world can be aligned to the virtual world to allow interactions that are meaningful in both worlds (e.g. in order to jump in the virtual world, you must do the same in the real world). By using such motion tracking technologies

[1] http://www.pokemongo.com/

[2] https://www.snapchat.com/

[3] https://developers.google.com/tango/

we are increasingly capable of escaping the isolation of the purely VR technologies and explore fully the "*mixed reality continuum*" [2]. Without motion tracking the virtual self is paralyzed, unable to move around in the virtual environment having to rely on an abstract control system like a gamepad to interact with the virtual world [45]. Motion tracking, on the other hand, inputs the user's movements into the virtual setting, translating them into natural interactions with the digital world. This avoids users having to learn a new interaction model, but raises new challenges for the HCI community, in particular how interaction is supported in motion tracking enhanced MR systems. Therefore we have identified an opportunity to study how the use of motion tracking capabilities can impact the user experience in a MR storytelling experience.

In this paper, we contribute to the field of MR firstly, with the development of a prototype that supports interactions with different DOF. Furthermore, we contribute by presenting the results of a three-pronged study designed to evaluate motion tracking effect on the user experience of a MR storytelling prototype. The study involves three versions of the same prototype environment where different DOF are affecting the user interaction with the story content. In Condition 1 (C1 – "ScreenUI") we chose a baseline interaction where we relied on virtual joysticks, for navigation and orientation, no motion tracking involved. In Condition 2 (C2 – "HybridUI") we relied on virtual joystick for navigation within the VE and in motion tracking of the user for orientation in the VE, which is a hybrid condition between 1 and 3. Finally in Condition 3 (C3 –"SpatialUI") we relied solely on the motion tracking capabilities of the device as input method for navigation and orientation within the VE (as participants walk and move the device around they change their position and perspective in the VE).

The interaction technique used for navigation input, increases in terms of the supported degrees of freedom from condition to condition, leading to a potential increase in physical body movement. We studied how this impacted positively the user levels of Presence, Flow and Immersion among others, through qualitative and quantitative methods.

RELATED WORK

Milgram and Kishino's [24] define Mixed Reality within the "*Reality Virtuality Continuum*", encompassing Physical Reality, Augmented Reality and Virtual Reality. Combining Mixed Reality with a ubiquitous knowledge of the world forms what Dourish calls a "*ubiquitous human media*" [10]. Moreover, Cheok illustrates [6,7,13], how ubiquitous human media" actually pushes people to become fully involved in social and physical and natural interactions [4,6].

Immersion is also a desired feeling among mobile MR experiences since it may lead to the Sense of Presence [34]. Presence is defined as psychological emergent property of an immersive system, and refers to the participant's sense of "*being there*" in the virtual world [44]. In a MR experience, participants need to be immersed in the virtual aspect of the experience but are still aware of their surroundings even if only for safety reasons. Due to the nature of MR, participants might never achieve full immersion [24] but a higher immersion might result in a stronger symbiosis between the virtual and the real world.

How do we interact within such MR experiences and make them compatible with real world environments is still a rich research field with many open questions. A more substantial body of work can be found if we turn to the VR field, where the study of immersive types of input for traditional VR systems and VR Head Mounted Displays (HMDs) has been investigated.

Initially, traditional VR systems restrained the users to their desk and limit their interactions with the virtual environment by enabling navigation through pointing devices, keyboards and game controllers [13]. Studies have demonstrated that the effectiveness of a VE is related with the sense of presence reported by users of those VE, therefore high levels of Presence are seen as desirable [44].. Slater et al. showed that interaction techniques in VR may play a crucial role in the determination of Presence [34]. Such results are corroborated by Templeman et al's survey summarizing some of those interaction techniques [38]. Moreover, various metaphors for viewpoint motion and control in 3D environments have been proposed. Ware et al. identify the "*flying*," "*eyeball-in-hand*," and "*scene-in-hand*" metaphors [43]. A fourth metaphor, "*ray casting*", [15] was suggested, which can be used to select targets for navigation. Others make use of a "*World-in-Miniature*" representation as a device for navigation and locomotion in immersive virtual environments [28,37]. All the mentioned approaches rely on a abstract representations of the physical controls movements.

However, VR research argued for the power of using of the whole body in VR Enviroments, to increase Immersion and Presence feelings [5]. Consequently, several user studies concerning immersive travel techniques have been reported in the literature, such as those comparing different travel modes and metaphors for specific virtual environment applications [8]. Physical motion techniques were also studied, such as the use of a "lean-based" technique [12]. In Slater et al.'s study [35] indicated that naive subjects in an immersive virtual environment experience a higher subjective sense of presence when they locomote by walking-in-place ("*virtual walking*") than when they push-button-fly ("*along the floor plane*"). Later this study was replicated, adding real walking as a third condition [42] showing higher scores for the Presence for people who did real walking.

A different approach was to rely on building supporting platforms to enable body movement such as treadmills equipped with individually height-adjustable elements that simulated bumpy terrain and virtual slopes [26] or the CirculaFloor, which uses four robot units that place themselves under the user's steps [17]. However these were bespoke that remained mostly as research prototypes.

More recently, technologies such as Oculus Rift[4] (with touch controllers), HTC Vive[5] and PrioVR[6] have been leading to the adoption and experimentation of new range of interaction techniques, with the goal of facilitating the transition between the physical world and the virtual world. Lopes et al. designed and tested mechanical devices targeted at providing electrical muscle stimulations such as stepping onto uneven ground [22] or the haptic sensation of hitting and being hit [21]. The work of Tregillus and Folmer, VR-DOP and VR-STEP prototypes, use the smartphone's inertial sensor to simulate walking in mobile VR demonstrating that walking in place provides an immersive way to achieve virtual locomotion in mobile VR [39,40]. McGill et al. [23] enhanced VR environments with elements of reality to correct typing performance and interaction with objects impairments. Their work is grounded on previous research showing that users immersed in a VR experiences perform better if it displays the sensory data related to their surroundings [34]. With the incorporation of real world elements, research in VR is converging with MR. However while trying to bridge virtual and real worlds, some of the above examples introduce complementary technologies, that usually require complicated setups to give more Agency and Immersion to the experience, eventually leading to complex and unnatural interactions. To avoid this issue we focus on prototyping through technology that is accessible, mobile and self contained but that at the same time promote a bridging between the virtual and real world while providing a natural interaction.

The release of Project Tango fomented a series of experimental concepts embracing the motion control abilities in several domains from games to education. Garden is a MR experience [33] enabling players to transform their real environment into a virtual garden were they can play in, using Project Tango device as a HMD. Ghostly Mansion [30] is a first person story-driven hidden object game for the Project Tango device, where the player explores virtual rooms looking for hidden objects related to the story narrative. Project Tango applications also covers commercial functionalities with applications such as Car Visualizer [27] (to view, walk around and interact with 3D representations of purchasable cars) or Home AR Designer [11] (that enables you to over impose furniture in your home before you buy it, taking into account the real dimensions of the space). Additionally to sandbox experiences (VRMT: Worldbuilder [9] and Tango Minitown [20]), there are Project Tango application with educational purposes such as Project Tangosaurs [29] or Solar Simulator [1], that enable users to explore rich virtual content (in this case, dinosaurs and planets) as if they were in a museum setting. Finally, the capabilities of devices such as Project Tango has started to be explored in other realms such as Assistive Technology with obstacle recognition and avoidance for the visually impaired [18]. The emergence of this applications across different fields suggest the importance of studying the role of motion tracking in user experience.

In our work, we identify a gap in the study of interaction techniques applied to MR experiences. We draw inspirations from related work in the VR field, specifically Slater et al.'s study [35], learning how motion tracking in VR has positively affected the users' experience. We set up our study to look at how motion tracking as an interaction technique, affects the users experience in a MR storytelling experience in terms of Presence and several game experience components.

MIXED REALITY EXPERIENCE: "THE OLD PHARMACY"

Our study focuses on a MR story-driven interactive experience entitled "The Old Pharmacy" from the reconstruction of a 19th century pharmacy as the narrative environment. "The Old Pharmacy" is one of the components of a larger transmedia story. In this scene, the protagonist of the story (Laura) attempts to make a medicinal drink. In order to complete the task, she needs to search through her establishment to find the right ingredients. The user, embodying the character of Laura, must explore the environment and find the necessary ingredients. During this process, the user is informed about the qualities and benefits of such products through the dialogue between characters. Accomplishing this task requires the users to navigate and orient themselves in the virtual environment.

Figure 1. "The Old Pharmacy" Mixed Reality Experience

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[4] www.oculus.com

[5] www.htcvive.com

[6] www.priovr.com

"The Old Pharmacy" interactive scene was built using Unity 5 game engine[7], using the Project Tango plugin[8] for device support and the Fungus SDK plugin[9] as a framework for the story narrative.

STUDY: IMPACT OF MOTION TRACKING IN THE USER EXPERIENCE

Research Design

Inspired by Slater et al.'s study applied to VR [35], we designed our study with three different interaction conditions to test potential impact of motion tracking in the user experience. In each condition, the participants are presented with a different way of navigating and orienting themselves within the "The Old Pharmacy" environment. As mentioned before, to fulfill the proposed task, participants have to navigate and look around the virtual environment. This interaction required for navigation and orientation differs in each condition (as can be seen in Table 1 and Figure 2). The action of interacting with selectable objects is the same across conditions (the participant touches the objects on the screen to select it).

Table 1. Summary of the conditions and respective interaction techniques

Condition	Required action by the participant		
	Orientation	*Navigation*	*Selection of Objects*
C1 "ScreenUI"	Virtual Joystick (Right side)	Virtual Joystick (Left side)	Touch input
C2 "HybridUI"	Physically rotating the device	Virtual Joystick (Left side)	Touch input
C3 "SpatialUI"	Physically rotating the device	Physical Walking	Touch input

The first condition is our baseline where the interaction within the virtual environment is achieved by using touch in virtual joysticks, one to look around and one to navigate. In this condition, no motion tracking capabilities are used; moreover, we chose the virtual joysticks as it is a common practice for first person mobile games. In the second condition, we used the mobile device's gyroscope and accelerometer to control the user's orientation and touch to control the navigation in the virtual world, through the virtual joystick. We considered this as a hybrid solution as it mixes virtual controls (navigation) with motion tracking control (orientation). Finally, in the third condition, the users interaction relies solely on the motion tracking capabilities of the Google Tango for navigation and viewpoint orientation. By allowing the same sensory–motor relations to exist between the user and the two worlds (real world and the virtual world), we aim for the experience to achieve a higher sense of realism. For an illustration of each of the conditions see Figure 2.

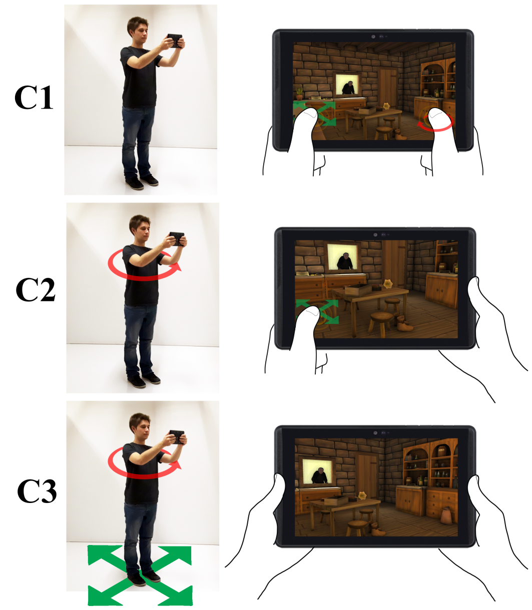

Figure 2. Interaction techniques for Conditions C1 (ScreenUI), C2 (HybridUI) and C3 (SpatialUI). Green arrows represent navigation actions and red arrow represent looking actions.

To note that participants are exposed to a small tutorial on the navigation input (according to their specific study condition) before moving on to the story portion of the scene. This was done in order for participants to get familiar with navigation before interacting with "The Old Pharmacy" story.

Demographics

A total of 36 users (38.9% females) were recruited for the study using the university mailing list. Participants' ages ranged between 18 and 44 years, in which 27.8% were less than 25 years, 63.9% were within the 25-34 age range and 8.3% were above 34 years old. All participants were, however, pre-screened for their fluency in English, since the majority (80.5%) had Portuguese as their native language were they lived [rem. for blind review]. Participants were randomly assigned among the three interaction conditions with different degrees of freedom (12 participants per condition).

Procedure

The trial was carried out in a controlled environment, a large classroom without furniture except for a chair and a table for the researcher (equipped with a video camera and a laptop to monitor the experience). Upon arriving,, participants were given a debriefing statement explaining the experiment in detail and consent forms to fill. Participants were asked to fill a pre-experience short

[7] https://unity3d.com

[8] http://fungusgames.com/

[9] https://developers.google.com/tango/apis/unity/

questionnaire to gather demographics and previous experience with smartphones, gamepads, games, VR and HMD and the Immersive Tendencies Questionnaire (ITQ) [44], developed to identify real world tendencies that may affect a person's sense of Presence. This pre-questionnaire allowed us to ensure the participants homogeneity across conditions in terms of technological experience and immersion abilities. The ITQ scale had a satisfactory internal reliability (Cronbach's $\alpha = 0.733$). Posteriorly we ran an ANOVA to check if for differences in terms of across the three conditions, results show that there are no significant differences between the ITQ scores [$F(2, 32)=0.295$ $p=0.746$]. We also ran a Kruskal-Wallis test in the Likert items related to previous game experience, VR and HMD and smartphones and no significant differences were found across the three conditions.

After filling out the survey, participants were handed a tablet device containing the "The Old Pharmacy". While the participants experienced the MR environment, the researcher was sitting in the back of the room, observing the participants and taking notes, not interfering with the study unless specifically asked by the participants. The researcher paid special attention to participant signs of struggle or ease while interacting with the device. These notes were used to inform questions for the unstructured interview.

Figure 3. Participants experiencing the "The Old Pharmacy"

Right after the participants completed the experience, they were asked to fill out the a survey composed by the core module of the Game Experience Questionnaire (GEQ) [16], and the Igroup Presence Questionnaire (IPQ) [32] this was done so that they would recall as much as possible from the experience.

The researcher conducted an unstructured interview based on the observations notes, together with some general questions about the overall experience, perceived interaction and content. Finally, participants were asked to fill out the post-game module of the Game Experience Questionnaire (CEQ), [16] on how they felt after the experience.

The overall session time took around 45 minutes per participant. The interaction with the "The Old Pharmacy" scene would take approximately 10 minutes, while the pre-questionnaire 5 minutes and the post game questionnaires and interview would take approximately 30 minutes.

Measures

Igroup Presence Questionnaire (IPQ)

Through this study we intend to validate if Presence, is affected by different degrees of freedom provided by the different navigation inputs. Turner [41]considers Presence a possible desirable state in MR environments. Based on this, we think is important to find out if Presence can be affected by different degrees of freedom in experiencing MR. Therefore, we used the validated IPQ to asses Presence in virtual environments. The questionnaire is composed by 14 Presence items in a seven point rating scale. The total Presence score in calculated by the sum of all the items. Furthermore, the IPQ is composed by three subscales:

- Spatial Presence - the sense of being physically present in the VE.
- Involvement - measuring the attention devoted to the VE and the involvement experienced.
- Experienced Realism - measuring the subjective experience of realism in the VE.

Game Experience Questionnaire (GEQ)

The GEQ [16] is a modular questionnaire that assesses different aspects of the subjective experience of playing a game. We apply this questionnaire to evaluate our MR experience since our experience possesses game mechanics such as exploring the environment in search for objects to complete the task. The GEQ possesses three different modules, however for this study we used only two of them. The core module of 33 items in a five-point rating scale identifies 7 components (Sensory and Imaginative Immersion, Flow, Competence, Positive Affect, Negative Affect, Tension, and Challenge) focusing on the in-game experience. The post-game module of 17 items in a five-point rating scale identifies 4 components (Positive Experience, Negative Experience, Tiredness, Returning to Reality) focusing on the aftermath of the game experience. Considering that other scales used in our study were of seven-point rating scales, we adapted our GEQ to support the seven-point rating scale and maintain consistency across answers.

Quantitative Data Results

The IPQ scale revealed a satisfactory internal reliability (Cronbach's $\alpha = 0.734$), with the reversed item *Presence in Virtual Space* removed. Additionally, the GEQ core module and GEQ post-game module, both presented satisfactory internal reliability (Cronbach's $\alpha = 0.804$ and Cronbach's $\alpha = 0.787$, respectively).

After accessing the normality of the sample, a one-way between-groups (condition 1, 2 and 3) analysis of variance was conducted to explore the impact of degrees of freedom on levels of Presence, in-game Game Experience and post game Game Experience, as measured by the IPQ and the core and post games modules of GEQ, respectively.

Table 2. Mean Score for IPQ

	Total Presence	***Experienced Realism***	***Spatial Presence***	***Involvement***
C1 "Screen UI"	M=3.83 SD=0.58	M=3.50 SD=0.90	M=4.00 SD=1.11	M=4.00 SD=0.82
C2 "Hybrid UI"	M=3.97 SD=0.62	M=3.2 SD=0.89	M=4.31 SD=1.38	M=4.42 SD=0.84
C3 "Spatial UI"	M=4.66 SD=0.52	M=4.31 SD=1.07	M=5.06 SD=0.44	M=4.60 SD=0.80

IPQ Results

There was a statistically significant difference at the p<0.05 level in the scores of *total Presence* across conditions [F(2, 33)=6.931, p=0.003]. A Post-hoc using Tukey HSD revealed that the mean score of *total Presence* was lower in C1-"ScreenUI" than in the other two conditions. We also analysed separately each of the Presence components (*Spatial Presence, Involvement, and Experienced Realism*). There was a statistically significant difference at the p<0.05 level in *Experienced Realism* scores across conditions [F(2, 33)=4.17, p=0.24]. Post-hoc comparisons using the Tukey HSD test indicated that the mean score of *Experienced Realism* for C2-"HybridUI" was significantly lower than in C3-"SpatialUI". C1-"ScreenUI" did not differ significantly from either C2-"HybridUI" or in C3-"SpatialUI". Regarding *Spatial Presence*, there was a statistically significant difference at the p<0.05 level, using Brown-Forsythe test, across conditions [F(2, 33)=3.22, p=0.06]. Post-hoc comparisons using the Tukey HSD test indicated that the mean score of *Spatial Presence* for C3-"SpatialUI" was significantly higher from C1-"ScreenUI". C2-"HybridUI" did not differ significantly from either C1-"ScreenUI" or C3-"SpatialUI".

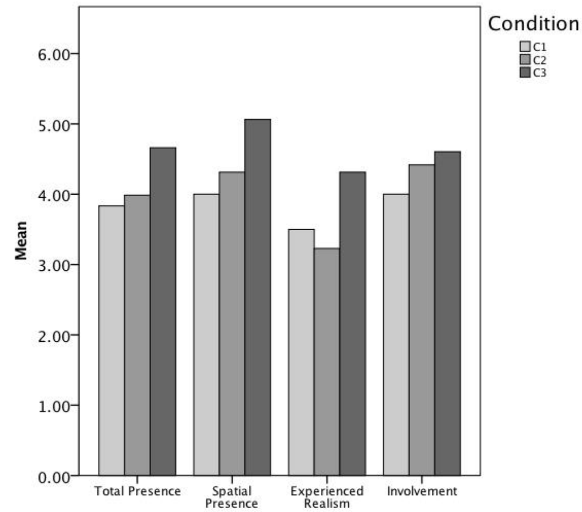

Figure 4. Bar graph chart for mean scores of IPQ components. All components are statistically significant expect for *Involvement* component.

GEQ Results

In relation to GEQ core module components, we found a statistically significant difference at the p<0.05 level in *Sensory and Imaginative Immersion* total scores across conditions [F(2, 33)=4.545 p=0.018]. A Post-hoc using Tukey HSD revealed that the mean score of *Sensory and Imaginative Immersion* was higher in C3-"SpatialUI" than in the other two conditions). We also found a statistically significant difference at the p<0.05 level in *Flow*

Table 3. Mean Scores and Standard Deviation for GEQ.

	GEQ Core Module							**GEQ Post-Game**			
	Competence	*Sensory Imaginative*	*Flow*	*Tension/Annoyance*	*Challenge*	*Negative Affect*	*Positive Affect*	*Returning to reality*	*Tiredness*	*Positive Experience*	*Negative Experience*
C1	M=3.90 SD=1.16	M=4.29 SD=0.95	M=3.80 SD=0.72	M=1.69 SD=0.82	M=2.28 SD=0.83	M=2.44 SD=1.07	M=4.70 SD=0.72	M=1.86 SD=0.52	M=1.67 SD=0.65	M=3.49 SD=0.80	M=1.64 SD=0.50
C2	M=4.45 SD=0.65	M=4.35 SD=0.97	M=3.80 SD=1.11	M=1.91 SD=0.698	M=2.78 SD=0.91	M=2.40 SD=0.78	M=4.83 SD=0.69	M=2.17 SD=0.67	M=1.86 SD=0.678	M=3.53 SD=1.08	M=1.78 SD=0.50
C3	M=4.36 SD=1.00	M=5.33 SD=0.94	M=4.85 SD=1.07	M=1.53 SD=0.63	M=2.35 SD=0.965	M=2.0417 SD=0.53	M=5.5818 SD=0.98	M=2.67 SD=0.910	M=1.29 SD=0.54	M=4.54 SD=1.57	M=1.53 SD=0.54

component total score across [F(2, 33)=4.347, p=0.019]. A Post-hoc using Tukey HSD revealed that the mean score of *Flow* was higher in C3-"SpatialUI" than in the other two conditions. Finally, there was a statistically significant difference at the p<0.05 level in *Positive Affect* scores across conditions [F(2, 33)=2.56, p=0.029]. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for C3-"SpatialUI" was significantly higher from C1-"ScreenUI". C2-"HybridUI" did not differ significantly from either C1-"ScreenUI" or C3-"SpatialUI".

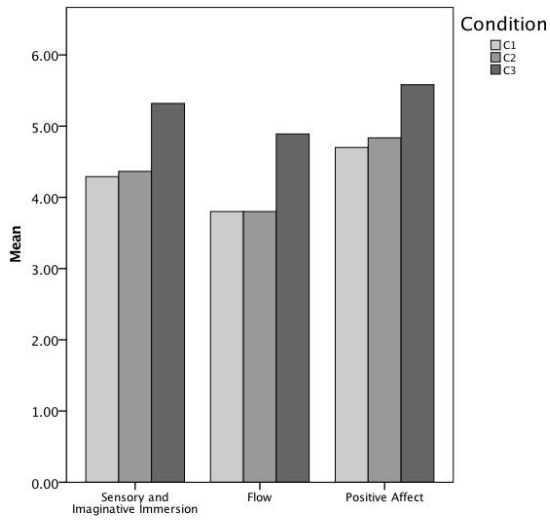

Figure 5. Bar graph chart for mean scores of statistically significant GEQ Core module components.

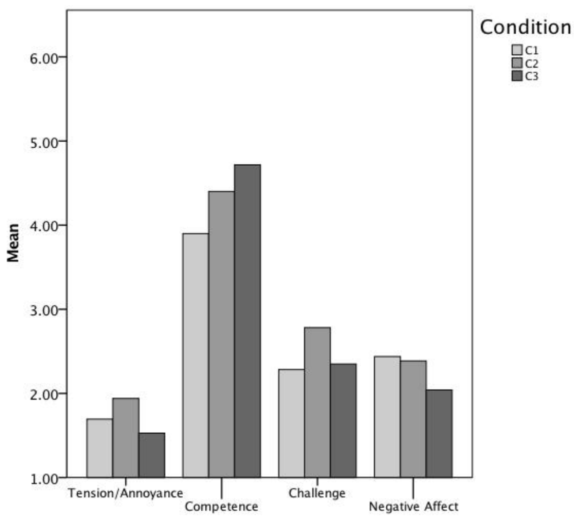

Figure 6. Bar graph chart for mean scores of GEQ Core module components without statistical significance.

In relation to GEQ post-game module components, There was a statistically significant difference at the p<0.05 level in *Returning to Reality* component scores across conditions [F(2, 33)=1.985, p=0.032]. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for C3-"SpatialUI" was significantly different from C1-"ScreenUI". C2-"HybridUI" did not differ significantly from either C1-"ScreenUI" or C3-"SpatialUI".

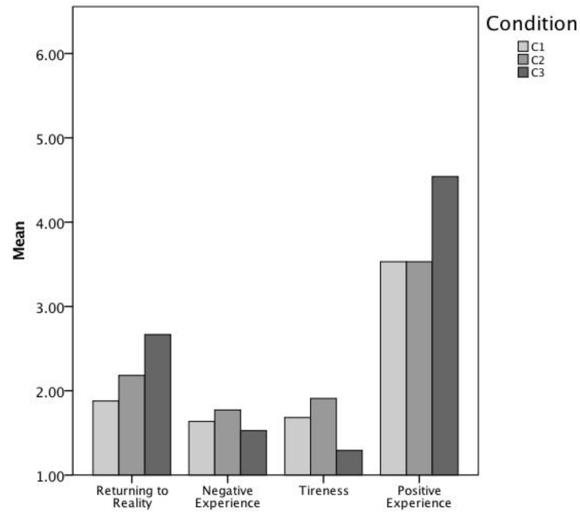

Figure 7. Bar graph chart for mean scores of GEQ Post-game module components. All components are not statistically significant except for *Returning to Reality* component.

Correlations

Analysing the overall sample, we found that *Sensory and Imaginative Immersion* was correlated with *Flow*, with a Pearson correlation, where results indicated a strong and positive correlation ([r = 0.625, n = 35, p = 0.02]). *Sensory and Imaginative Immersion* was also correlated with *total Presence*, with a Pearson correlation, where results indicated a medium and positive correlation ([r = 0.381, n = 36, p = 0.05]) in which high levels of *Sensory and Imaginative Immersion* were associated with high levels of *Presence*. *Sensory and Imaginative Immersion* was also correlated with *Positive Experience*, with a Pearson correlation, where results indicated a strong and positive correlation ([r = 0.610, n = 35, p = 0.01]). Finally, *Sensory and Imaginative Immersion* was correlated with *Positive Affect*, with a Pearson correlation, where results indicated a strong and positive correlation ([r = 0.799, n = 35, p = 0.01]). *Returning to Reality* was correlated with *Positive Experience*, with a Pearson correlation, where results indicated a strong and positive correlation ([r = 0.551, n = 35, p = 0.01]) and correlated with *Positive Affect*, with a Pearson correlation, where results indicated a medium and positive correlation ([r = 0.359, n = 35, p = 0.05]). *Experienced Realism* was correlated with *total Presence*, with a Pearson correlation, where results indicated a strong and positive correlation ([r = 0.784, n = 36, p = 0.01]) and correlated with *Flow*, with a Pearson correlation, where results indicated a medium and positive correlation ([r = 0.338, n = 35, p = 0.05]).

On the other hand, and opposed to what we expected, we did not find significant correlation between prior experience with smartphones and virtual reality and the total score and components scores of IPQ and components of GEQ.

Additionally, we did not find a correlation between the participant's Immersive Tendencies and the total score and components scores of IPQ and components of GEQ.

Qualitative Data Results

After gathering all the information expressed by participants during the unstructured interviews, a team of two researchers used open coding, where each researcher selected quotes and created high-level categories, they were then reviewed and merged or divided into new categories, described below. We identify the participants' quotes with the condition and their session ID (eg: C1-P30 – Condition 1 participant session 30).

Interaction

Most participants in C1-"ScreenUI" agreed that navigation was inadequate, reporting difficulties in adapting to the controls (C1-P30 *"Controls were a surprise [...] I found them to control and to explore the virtual environment").* Moreover, the need for high cognitive effort to calculate movement in order to achieve accurate navigation was mentioned. In C2-"HybridUI", the number of users exposing this problem was lower, (C2-P40 *"I felt that I always had to be calculating my movement and my gaze.",* C2-P33 mentioned confusion in the beginning of the experience *"Using both joystick and my arms to pinpoint place and things was a bit confusing in the beginning"*). In C3-"SpatialUI", one user demonstrated to the interviewer some disapproval towards the interaction mode (C3-P21 *"If I wanted to look back, I felt forced to turn my whole body back").*

In C1-"ScreenUI" and C2-"HybridUI", fewer participants specifically mentioned the comfortable navigation (no tiredness, stress or pain), than in C3-"SpatialUI" (C3-P9 "*Walking around the room was an interesting experience; the control of the movement felt natural."*). However at least 2 participants specifically mentioned the possibility of an uncomfortable navigation if the experience was longer (C3-P20 "If the story was bigger, I would feel very tired, arms mostly, and concerned since the tablet gets hot.").

Participants Motivations

From the interviews, we noticed the emergence of three patterns of participants in terms of their engagement with the experience and we classified them according to what they expressed in the interview. The first, "competitors", are participants motivated to complete the task in the least amount of time (e.g. C1-P3 *"I'm competitive so I always felt great when I found an object belonging to the quest.",* C2-P35 *"[I] wish I could skip the unnecessary dialogue."*). The second, "explorers", are participants who would scan the environment, touching and interacting with any interactable object (C3-P19 *"I enjoyed being able to interact with lots of objects in the VE. It made me feel in control.").* Finally, the third profile, "role-players", were participants that felt driven by the character's quest in choosing items and found meaning in them (C1-P27, *"The audio dialogue was important for me to feel part of the story. I would even stop to hear them."*). In C1-"ScreenUI", we identified 4 competitors, 5 explorers and 3 role-players. In C2-"HybridUI", we identified 5 competitors, 3 explorers and 4 role-players. Finally, in C3-"SpatialUI", we identified 5 competitors, 1 explorer and 6 role-players.

Immersion in MR

More participants from C2-"HybridUI" and C3-"SpatialUI" than from C1-"ScreenUI", expressed to the researcher conducting the interview, feeling immersed and a sense of being in the virtual world (C3-P15 *"I had the sense that I, as a whole, got sucked into the virtual world. You just need to always keep mindful about where you step",* C3-P19 *"I definitely felt part of the game. I walked to places to get my ingredients, I looked up and down to explore and, I was talking to a client."*). However participants from all the conditions explicitly felt like they were adding to the story and content (C3- P19 *"I enjoyed being able to interact with lots of objects in the VE. It made me feel in control."*, C1-P27 *"I felt like I was building the story through the objects"*). A couple of participants mention that the task given was short for them to really feel engaged and immersed. For example, C2-P44 said: *"I could not feel any empathy with the characters. I had no time to get to know them and get passionate about their struggles."*

Sense of Body

Across all conditions several users made remarks regarding their sense of body in the MR environment. Some of the comments touched upon the relationship between the scale of the room and the their size within it. Some users reported feeling big while, others felt like they were smaller than their real self. For example, C1-P23 *"I felt both tall and short. When looking up, the ceiling was to close. When looking down I felt too close to the ground."* Or C2-P35 *"I felt shorter in the game. The place that I recall I felt this mostly is near the window, as you look to the old lady, you get the sense she is quite tall."* Some users enjoyed this different sensation C2-P42 "*[...] I felt quite tall. It was a good sensation",* C3-P4 *"I got the feeling I was shorter than I am [...] I found it interesting. It was like being in a hobbit house."*. Participants from C1-"ScreenUI" and C2-"HybridUI", did not mention any experienced different in relation to the mapping of the navigation with the provided interaction mode, while in C3-"SpatialUI" the mapping between the navigation in the real world and the virtual world was noticed. C3-P16 mentioned *"I felt I walked faster in the game, than in the real world. It was good, since it would cover more ground on the game without taking too much of my real space."*

Some participants across all conditions also mention a desire to see their virtual body represented. They desired to see their hands while choosing the ingredients and their full body when looking down. C3-P17 *"The thing though, got strange when I first interacted with an object. I was expecting to see a hand picking it up." Or C3-P9, "When I* *looked down I was expecting to see my feet. I wanted to see myself walking.”*.

Awareness of Real Space

Participants in C3-“SpatialUI” were more aware of the real space, as several participants made comments about that. For example, one participant (C3-P17) initially thought that the tables in the real world were matching the tables in digital world. Another (C3-P16) mentioned that the real world space was smaller than the virtual. Awareness of the real space was also noticed thought comments regarding safety in walking. Some users expressed to be a ease while interacting (C3-P20 *“Unless there was holes in the ground, I felt safe playing the game”*; C3-P15 “*got sucked into the virtual world. You just need to always keep mindful about where you step.”*), while others expressed some concerns *(*C3-P16 *“I was worried about tripping in any of the chairs.”;* C3-P17 *“it needs a lot of space, if it’s bigger how can I play it safety?”).*

DISCUSSION

In general, from the overall score in the Presence and the Game Experience components, we can infer that any of the chosen interaction techniques would produce a satisfactory experience. In Positive Experience, all the mean scores are higher than 3.5. However when looking closely at certain components of the Presence and Game Experience, we can identify that condition C3-“SpatialUI” clearly produces a richer experience.

The total score of Presence was significantly lower in C1-“ScreenUI” in comparison to the other two conditions. Align with what we saw previously [34], virtual controls - an abstract control - can lead to a lower sense of presence. C2-“HybridUI” has a significantly lower score on Experienced Realism when compared against the other two conditions. The “hybrid” nature of C2-“HybridUI” (mixing the realism of “looking around” with an abstract control for navigation) does not correspond to the users’ expectation since the offer of a natural affordance for orientation clashes with the abstraction for the navigation. This finding is corroborated by observed users’ behaviours who walked in the real world (but with no correspondence in the virtual world). As we were expecting in the Spatial Presence component, the mean score are significantly higher in C3-“SpatialUI” as the participants’ actions with their real body, are reflected on actions within the virtual world, leading sense of being there. Finally, regarding the Involvement Presence component, results indicate that the interaction does not seem to affect the attention to real and virtual environment since there are no statically significant differences between the scores in any of the conditions. However, when looking at the mean values participants seem to be more aware of the real space in C3-“SpatialUI” aligning with what we found in the interviews (*C3-P17 “it needs a lot of space, if it’s bigger how can I play it safety?”)*

Looking at the GEQ core module scores, we found Sensory and Imaginative Immersion significantly higher for participants in C3-“SpatialUI” . “The Old Pharmacy” participants were engrossed in its atmosphere (both in terms of the audiovisual content and empathizing with the character). We infer that the use of the natural body movements as interactions facilitated the users in embodying the character of Laura. Although some participants complained about the lack of a virtual representation of the characters body, this issue did not affect their Sensory and Imaginative Immersion in C3-“SpatialUI” (*C3-P17 “I noticed that my character did not have a body. That was okay, as I felt that my body was in a sense, the vessel.”).* Similar to the previous component, the Flow scores also reveled to be statistically higher in C3-“SpatialUI” than in the other two conditions. According to Csíkszentmihályi, Immersion is a precondition to Flow [46]. Furthermore, we found a strong correlation between Sensory and Imaginative Immersion and Flow. Based on this finding, we can now confidently say that the use of higher DOF as interaction techniques has led to a higher degree of immersion and consequently higher values in Flow. Finally, C3-“SpatialUI” evokes the most Positive Affect from the users, since it has a statistically higher mean score when compared to the C1-“ScreenUI”; however, there is no statistically significant difference with the C2-“HybridUI”. There is an increase of the mean score as the DOF of each condition increases. Moreover, there is a correlation between the Sensory and Imaginative Immersion and the Positive Affect indicating that higher levels of Immersion lead to a higher Positive Affect during the MR experience. Opposed to what we were expecting, the levels of Positive Affect were not significantly higher in C2-“HybridUI” compared to C1-“ScreenUI”. One reason for this result is the values from the GEQ in the components for Tension/Annoyance and Challenge, higher for C2-“HybridUI” (although it did not reach statistical significance) indicating some of the difficulties in interaction reflected on Positive Affect scores. We believe that this difficulty in interaction arouse from the effort reported by the users in combining the virtual control for navigation with the rotation of the tablet to look around as mentioned by the participant C2-P33 *“Using both joystick and my arms to pinpoint place and things was a bit confusing in the beginning”*.

Regarding the GEQ post game module it not surprising that for users in C3-“SpatialUI” it was significantly harder to return to reality that in C1-“ScreenUI”, since the Sensory and Imaginative Immersion was also higher in C3-“SpatialUI”.

CONCLUSION AND FUTURE WORK

In this paper, we report on the design and evaluation of a MR storytelling prototype where we set to study how different interaction techniques enabled by different DOF, affect the user experience. We designed a study to evaluate different interaction techniques and their effect on desirable aspect of user experience (Flow, Presence, Immersion, Positive Affect among others). Overall our results show that using mobile depth technology enhances the user experience. The more DOF, the more users reported feeling in Flow, Presence and Immersed and positive feelings during as well as after the experience ended. However there are many challenges that such freedom can bring, like safety concerns (in real world situations) and ergonomic concerns (when considering longer experiences).

In summary, our findings point towards how using depth sensing coupled with a Mixed Reality storytelling experience can bring a higher awareness of the real world surroundings, and does not detract from Immersion and Presence in the experience. In fact bringing interaction involving sensory-motor effects and having these coupled in the virtual and the real worlds leads to a higher realism in the mixed reality experience. However, further studies need to be conducted, specifically using similar experience in real world context and with a longer duration.

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