Step by Step: Evaluating Navigation Styles in Mixed Reality Entertainment Experience

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Abstract. The availability of depth sensing technology in smartphones and tablets adds spatial awareness as an interaction modality to mobile entertainment experiences and showcases the potential of Mixed Reality (MR) for creating immersive and engaging experiences in real world contexts. However, the lack of design knowledge about interactions within MR represents a barrier to creating effective entertainment experiences. Faced with this challenge, we contribute a study of three navigation styles (NS) for MR experiences shown on a handheld device. The navigation styles range from fully virtual, through a mixed style that involves both on-screen and in-world activity, to fully real navigation. Our findings suggest that when designing an MR experience, the navigation style deployed should reflect the context, content and required interactions. For our MR experience, "The Old Pharmacy", with its specific content, context and required interactions, results show that navigation styles relying on in-world activity leads to higher levels of Presence, Immersion and Flow.

Keywords: Mixed reality · Mobiles devices · Depth perception
Navigation style · User experience · User study

1 Introduction

After many years of promising research, virtual and augmented reality systems are becoming mainstream. The next generation of mobile and wearable devices, such as Google's Project Tango [1] and Microsoft's HoloLens [2], combine high-resolution graphics with sophisticated tracking and scanning systems. These devices enable consumers to access rich Mixed Reality (MR) spaces where digital and physical objects can interact in real time in application areas as diverse as gaming [3] education [4] and navigation [5, 6]. They promise advantages and benefits in terms of delivery of contextual information [7] and in supporting increased levels of user presence [8].

However, MR systems are highly diverse, spanning the spectrum of the Reality-Virtuality Continuum (RVC) [9] from entirely virtual to fully real. This diversity presents considerable challenges to designers, as there is a lack of design knowledge relating to how systems at different positions on the RVC spectrum will impact the experiences of their users. While this is true for a wide range of application areas, we believe it is particularly relevant to the domain of entertainment, where experiential

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qualities such as immersion, engagement and fun are foregrounded. We argue that, as MR applications and use cases become more commonplace, it is important to understand how interaction techniques impact user experience and engagement in entertainment focused MR contents and applications.

In this paper, we contribute to advancing the understanding of MR entertainment experiences by studying the impact of Navigational Styles (NS) on the user experience of MR environments. This is valuable as navigating around digital content is a core feature of MR scenarios. Users can navigate MR environments by a range of mechanisms that parallel the RVC itself, from the use of controllers in virtual environment to fully real navigation in the physical world. Different styles result in very different experiences and, we argue, will translate into different entertainment outcomes.

The main contribution of this paper is a systematic study of the influence of navigation styles used in MR experiences supporting a range of on-screen and in-world activities. First, we classify three navigation styles covering the RVC: (i) *Screen* (virtual based), (ii) *Hybrid* (involving on-screen and in-world) and (iii) *Spatial* (in-world). We then contrast these styles in terms of measures of presence, game experience and qualitative comments captured from participants in order to evaluate which navigation style provides a better experience from an entertainment point of view. Our findings reveal that a NS with in-world activity is preferred to a NS with virtual controls when trying to achieve higher levels of Presence, Immersion and Flow. Based on these results, we also contribute a discussion of how content, context and required interactions can inform designers' choice of a NS to better support compelling entertainment experiences.

2 Related Work

Milgram and Kishino's [10] 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*" [11]. Moreover, Cheok illustrates [12–14], how ubiquitous human media actually pushes people to become fully involved in social, physical and natural interactions [12, 15].

Immersion is a common word widely used to describe the level of involvement or engagement one experiences during activities such as playing games [16, 17]. It is relevant to mobile MR experiences as it may lead to increases in presence [18]. Presence is defined as an emergent property of an immersive system, and refers to the participant's sense of "*being there*" in the virtual world [19]. In a MR experience, participants need to be immersed in the virtual aspects of the experience but also maintain awareness of their surroundings for, at least, reasons such as safety. Due to the nature of MR, participants may never achieve full immersion [10] but greater immersion may lead to a stronger merging of the virtual and real worlds.

How to interact within MR experiences and navigation techniques are a core topic of study within both MR and VR communities. Indeed a substantial body of work can be found in the VR field, where the study of immersive types of input for traditional VR systems and VR Head Mounted Displays (HMDs) have been investigated.

Initially, traditional VR systems restrained the users to their desk and limited 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 it evokes; high levels of Presence are therefore seen as desirable [19]. Slater *et al.* showed that interaction techniques in VR play a crucial role in the determination of Presence [18]. These results are corroborated by Templeman *et al.*'s survey summarizing VR interaction techniques [20]. One theme within this research relates to the benefits of using the whole body in VR environments to increase levels of immersion and feelings of presence [21]. For example, numerous user studies concerning immersive travel techniques have been reported in the literature, such as those comparing different travel modes and metaphors for virtual environment applications [22]. Physical motion techniques were also studied, such as the use of a "lean-based" technique [23]. Slater *et al.*'s [24] 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 [25] and showing this achieve yet higher scores for the presence. Similarly, Hwang [26] compares perceived field of view (FOV), levels of immersion and presence, task performance and usability among users of various VR platforms including hand-held devices. The results highlight that motion based interaction, a unique characteristic of hand-held platforms, can help presence/immersion and the perceived FOV.

More recently, technologies such as Oculus Rift[1] (with touch controllers), HTC Vive[2] and PrioVR[3] have led to a new range of interaction techniques that seek to facilitate transitions between the physical and virtual worlds. Lopes *et al.* designed and tested mechanical devices targeted at providing electrical muscle stimulations such as stepping onto uneven ground [27] or the haptic sensation of hitting and being hit [28]. The work of Tregillus and Folmer [29, 30], the VR-DROP and VR-STEP prototypes, use a 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]. In fact, research shows that users immersed in VR experiences perform better if it displays the sensory data related to their surroundings [18, 31]. 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 rely on complex technologies that require highly specific sensing or actuation setups. As such they are unavailable to current MR designers using commodity technology solutions. To better target this group, the current research focuses on prototyping through technology that is accessible, mobile and self-contained. It seeks to explore how existing mobile technology can bridge between the virtual and real worlds, while still providing natural interaction and high level of immersion.

The release of Project Tango led to a series of experimental concepts embracing the motion control abilities in several domains from games to education. Garden is a MR

1 www.oculus.com.
2 www.htcvive.com.
3 www.priovr.com.

experience [3] enabling players to transform their real environment into a virtual garden where they can play in using Project Tango device as a HMD. Ghostly Mansion [32] 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 target commercial scenarios with applications such as Car Visualizer [33] (to view, walk around and interact with 3D representations of purchasable cars) or Home AR Designer [34] (that enables you to superimpose furniture in your home before you buy it, taking into account the real dimensions of the space). Additionally there are sandbox experiences (VRMT: Worldbuilder [35] and Tango Minitown [36]) and Project Tango applications with educational purposes such as Project Tangosaurs [37] or Solar Simulator [38]. These enable users to explore rich virtual content (in this case, dinosaurs and planets) as if they were in a museum setting.

In our work, we identify a gap in the study of interaction techniques applied to MR experiences that seek to entertain their users. We draw inspiration from related work in the VR field, specifically Slater *et al.*'s study [24], and Hwang's study [26] showing how motion tracking in VR positively affected the users' experience. Accordingly, the study in this paper looks at how different interaction techniques affect the users experience in a MR storytelling experience, with a special attention to the role of motion tracking. We analyse the user experience in terms of Presence and key game experience components such as flow and imaginative immersion. These are particularly relevant as prior literature has posited a link between feelings of Presence and "being in flow" during entertainment experiences [39].

3 MR Experience: "The Old Pharmacy"

"The Old Pharmacy" is an MR story-driven interactive experience where users explore a reconstruction of a 19th century pharmacy on a handheld device (Fig. 1). The user, embodying the character of the proprietor Laura, is asked by a virtual character (a customer) to make a medicinal drink by gathering four objects, spread around the virtual pharmacy. To accomplish this task, the user must navigate and orient themselves in the virtual world and examine the objects within it. The pharmacy is a visually complex environment with many objects distributed around the space both horizontally and vertically (e.g. on furniture). The search task requires the user to move around and explore different viewpoints. The experience features a total of 15 selectable objects. When a user is within reaching distance of one of these, the object is highlighted visually with a glow effect and a user can select it with an on-screen tap. An audio dialogue between the customer and Laura elaborates on the properties of the object. When an object that is part of the set of ingredients needed to make the drink is selected the user receives encouraging on-screen and auditory feedback.

"The Old Pharmacy" experience was built using the Unity 5 game engine [40] for the Project Tango platform. Using depth perception information and computer vision algorithms, Project Tango can reconstruct mathematical models of the real world over time. The system estimates the movement of the device in relation to the real world, allowing for motion tracking (navigation and orientation) of the user holding the device.

Abstracting from the technology behind it, this type of system showcases the potential of using knowledge of the surrounding world as input.

Fig. 1. "The Old Pharmacy" mixed reality experience with room layout (orange dots are selectable objects and green objects are selectable objects that need to be collected). (Color figure online)

4 Study: Navigation Styles in a MR Experience

4.1 Experimental Design

The study used a single independent variable: Navigation Style (NS). Three groups of participants experienced "The Old Pharmacy", each with a different NS (see Fig. 2). We used a between groups design, instead of a more powerful repeated measures design, as completing the experience once reveals the location of the key items and would strongly impact behaviour during subsequent runs through the system. The three NS are: *Screen*, *Hybrid* and *Spatial*. *Screen* is a baseline and interaction within the virtual environment is achieved by the common approach of manipulating two on-screen virtual joysticks, one to look around (view orientation) and one to walk (location). In the second style, *Hybrid*, we used the mobile device's gyroscope and accelerometer to control the user's orientation and a virtual joystick to enable navigation to different locations. Unlike *Screen*, this involves an MR experience, as device sensors translate the real world orientation into the virtual world. Finally, in *Spatial*, interaction relies solely on Project Tango motion tracking for controlling both orientation and translation. By creating a direct mapping between sensory–motor actions in both the real and virtual worlds, we aim to achieve a higher sense of realism and fidelity [41].

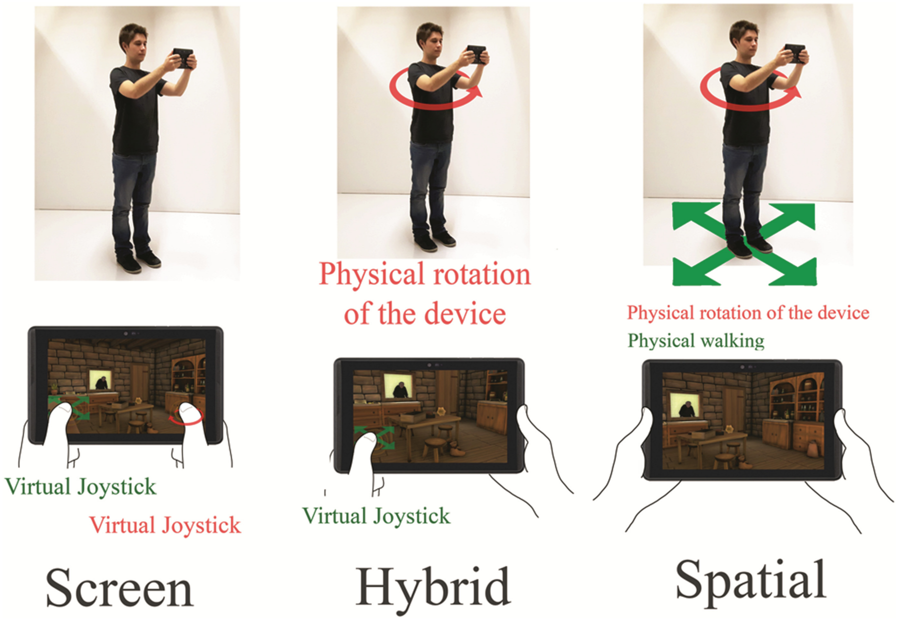

Fig. 2. Interaction techniques for conditions: *Screen*, *Hybrid* and *Spatial*. The green represents navigation actions and red represents looking actions. Objects are selectable by touch in all conditions. (Color figure online)

4.2 Demographics

We recruited 36 users (38.9% females) for the study using the university mailing list. Participants' ages ranged from 18 to 44 years (27.8% were less than 25 years, 63.9% within the 25–34 age range and 8.3% above 34 years old). Participants were randomly assigned among the navigation styles (12 per condition) and demographics captured previous experience with games, VR, HMD and smartphones on seven point Likert items. A Kruskal-Wallis test on this data showed no significant differences across the groups, indicating samples were homogenous.

4.3 Procedure and Measures

The trial was carried out in a controlled environment consisting of a 5 m by 6 m room without furniture. Participants were given a debriefing statement explaining the experiment in detail and signed a consent form. After completing demographics, they were handed a tablet device containing the "The Old Pharmacy" and given a short tutorial on the navigation style they were to use. They then completed the experience. Immediately after the trial, they completed a survey using the core module of the Game Experience Questionnaire (GEQ) [16], and the Igroup Presence Questionnaire (IPQ) [42]. The IPQ [43] features constructs of Spatial Presence, Involvement and Experienced Realism. Using it measures how the experience invoked a sense of Presence in the participants.

The GEQ seeks to capture in-the-moment qualities of a game experience and we expected that the GEQ modules components to vary amongst the three NS. The GEQ core module focuses on in-game experience by measuring Flow, Tension, Sensory and Imaginative Immersion, Competence, Positive Affect, Negative Affect, and Challenge, while the post-game module focuses on Positive Experience, Negative Experience, Tiredness and Returning to Reality.

Next, an experimenter conducted an unstructured interview, based on the observation notes, to capture comments on the overall experience and interaction with the system and content. Finally, participants completed the post-game module of the GEQ. This module captures a participant's opinions and reflections after an experience is complete. In total, each study session took around 45 min (10 min for the actual task).

4.4 Data Analysis

Scoring guidelines for each of the scales were followed to obtain the scores to measure the participants experience according to the navigation style. Due to the nature of data measured (ordinal data from Likert scales) and the small sample size, we performed separate non-parametric tests on each measure. These were one-way Kruskal-Wallis ANOVAs followed by Mann-Whitney *post-hoc* pairwise comparisons. We used an alpha value of $p < 0.05$. Due to the multiple comparisons made, Bonferroni corrections ($p < 0.05/3$) are typically applied. After careful consideration we opted to report the statistics without these corrections since we used non-parametric tests, which are in general more conservative. In the particular case of our study, performing Bonferroni corrections and specially taking into account the small sample size, could inflate type II errors [44]. Furthermore, in the interests of brevity, only significant results are reported.

4.5 Quantitative Data Results

IPQ data are plotted in Fig. 3. Kruskal-Wallis tests showed that the sense of Presence (Total Presence $H(2) = 11.18$, $p = 0.004$) was different depending on the NS. Pairwise comparisons showed differences between *Screen* and *Spatial* conditions ($U = 20.0$, $p = 0.03$, $R = -0.50$) and between *Hybrid* and *Spatial* conditions ($U = 26.0$, $p = 0.008$, $r = -0.45$). We also performed Kruskal-Wallis tests on all three IPQ constructs, only two showed that the NS significantly influenced ratings: Experienced Realism ($H(2) = 6.57$, $p = 0.037$) and Spatial Presence ($H(2) = 7.48$, $p = 0.024$). Pairwise comparisons showed differences between *Screen* and *Spatial* conditions for Spatial Presence ($U = 25.0$, $p = 0.006$, $r = -0.46$). Regarding the Experienced Realism pair wise comparisons revealed that there was a significant difference between *Hybrid* and *Spatial conditions* ($U = 31.50$, $p = 0.019$, $r = -0.003$).

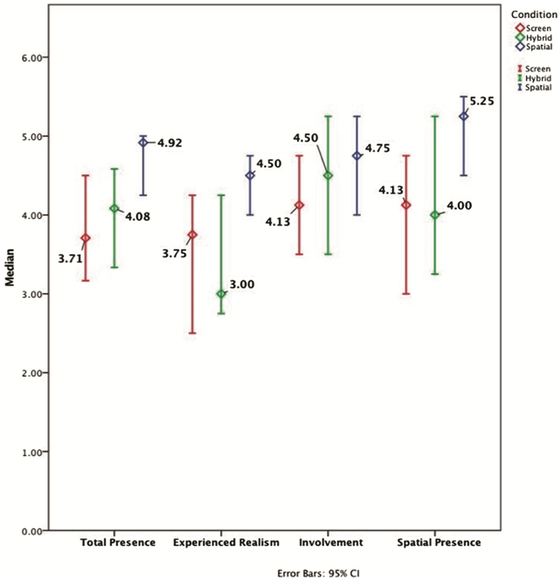

Fig. 3. Median scores of total presence and IPQ components *Experienced Realism*, *Involvement* and *Spatial Presence*

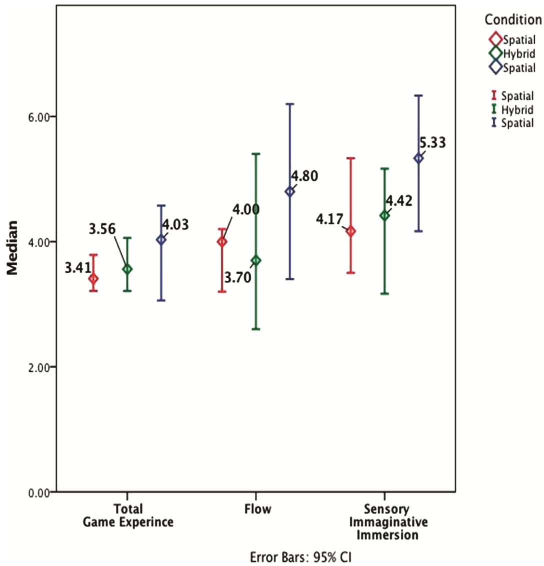

Fig. 4. Median scores for total GEQ and GEQ core module components Flow and Sensory and Imaginative Immersion

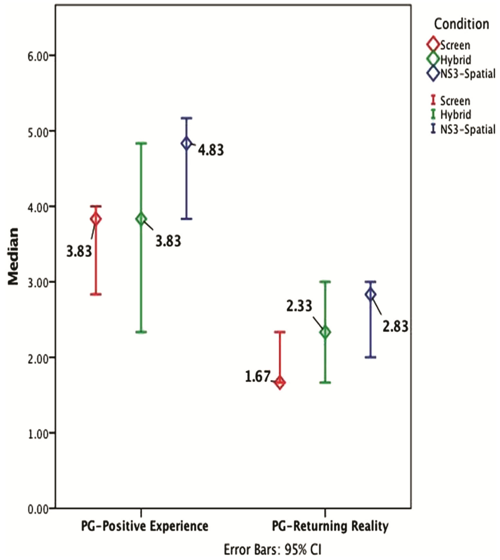

Fig. 5. Median scores for GEQ post-game components Positive Experience and Returning to Reality and error bars representing confidence intervals at the 95% level.

GEQ data are shown in Figs. 4 and 5. In terms of total game experience the Total GEQ scores demonstrated significant differences depending on the NS, ($H(2) = 6.47$, $p < 0.039$). A post-hoc test showed differences between the *Screen* and *Spatial* conditions ($U = 27.0$, $p = 0.016$, $r = -0.40$). We also ran Kruskal-Wallis tests on the GEQ constructs which led to significant main effects in Sensory and Imaginative Immersion (SII) ($H(2) = 6.75$, $p = 0.034$) and Flow ($H(2) = 8.42$, $p = 0.015$). Post-hoc tests showed differences in the two constructs in conditions *Screen* and *Spatial* (SII-$U = 31.0$, $p = 0.018$, $r = -0.39$; Flow-$U = 26.5$, $p = 0.008$, $r = -0.44$) and between *Hybrid* and *Spatial* conditions (SII-$U = 36.0$, $p = 0.037$, $r = -0.35$; Flow-$U = 28.5$, $p = 0.021$, $r = -0.39$).

In the post-game GEQ items, there were significant differences in ratings for the factors of Returning to Reality ($H(2) = 6.93$, $p = 0.031$) and Positive Experience ($H(2) = 6.91$, $p = 0.032$). Post-hoc tests bore these out between *Screen* and *Spatial* (respectively: $U = 28.5$, $p = 0.011$, $r = -0.42$ and $U = 31.5$, $p = 0.019$, $r = -0.39$).

4.6 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. These codes were then reviewed and merged or divided into new categories, as described below. We identify the participants' quotes with the navigation style and their session ID (e.g.: *Screen*-P30 – navigation style *Screen* participant session 30).

Interaction

Most participants in *Screen* agreed that navigation was inadequate, reporting difficulties in adapting to the controls (*Screen*-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 *Hybrid*, the number of users highlighting this problem was reduced, (*Hybrid*-P40 *"I felt that I always had to be calculating my movement and my gaze.", Hybrid*-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 *Spatial*, one user expanded on difficulties experienced with the interaction mode (*Spatial*-P21 *"If I wanted to look back, I felt forced to turn my whole body back").*

In *Screen* and *Hybrid*, fewer participants specifically mentioned the comfortable navigation (no tiredness, stress or pain), than in *Spatial* (*Spatial*-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 problems if the experience was longer (*Spatial*-P20 "If the story was bigger, I would feel very tired, arms mostly, and concerned since the tablet gets hot.").

Immersion in MR

More participants from *Hybrid* and *Spatial* than from *Screen* reported feeling immersed and experiencing a sense of being in the virtual world (*Spatial*-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", Spatial*-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 (*Spatial*-P19 *"I enjoyed being able to interact with lots of objects in the VE. It made me feel in control."*, *Screen*-P27 *"I felt like I was building the story through the objects"*). A couple of participants mentioned that the task given was short for them to really feel engaged and immersed. For example, *Hybrid*-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 their size within it. Some users reported feeling big while, others felt like they were smaller than their real self. For example, *Screen*-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 *Hybrid*-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 *Hybrid*-P42 "*[...] I felt quite tall. It was a good sensation", Spatial*-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 *Screen* and *Hybrid* did not mention experiencing differences in relation to how navigation input was mapped to response in the interaction modes. In contrast, in *Spatial* the mapping between navigation in the real world and the virtual world was noticed. *Spatial*-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 mentioned 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. *Spatial*-P17 *"The thing though, got strange when I first interacted with an object. I was expecting to see a hand picking it up." Or Spatial-P9, "When I looked down I was expecting to see my feet. I wanted to see myself walking."*.

Awareness of Real Space

Participants in *Spatial* were more aware of the real space; several participants commented about this issue. For example, one participant (*Spatial*-P17) initially thought that the tables in the real world were matching the tables in digital world. Another (*Spatial*-P16) mentioned that the real world space was smaller than the virtual. Awareness of the real space was also came across through comments regarding safety during walking. Some users were at relative ease while interacting (*Spatial*-P20 *"Unless there were holes in the ground, I felt safe playing the game"*; *Spatial*-P15 "*got sucked into the virtual world. You just need to always keep mindful about where you step."*), while others expressed concern *(Spatial*-P16 *"I was worried about tripping in any of the chairs."; Spatial*-P17 *"it needs a lot of space, if it's bigger how can I play it safely?").*

5 Discussion

The results show the *Spatial* condition produces a richer MR experience than the other two conditions in terms of a range of metrics from both the IPQ and GEQ. There are several caveats to this broad conclusion and we discuss the details below.

Interaction: The *Spatial* condition supports higher levels of presence than the baseline *Screen* and the *Hybrid* but in different ways. The first finding ties in with prior research [18] indicating that virtual controls lead to reduced presence compared to more natural navigation styles [8]. However, some aspects of presence were negatively affected by the *Hybrid* condition. Specifically, Experienced Realism dropped against the baseline. We suggest this is because the "hybrid" interaction scheme does not have a direct analogy in the real world - although its natural to control orientation in the scene with similar movements of the device, its challenging to integrate this real world activity with traditional on-screen input to control position. This finding is corroborated by observed user behaviour: participants walked in the *Hybrid* condition, despite the fact this had no impact on the game world. The *Spatial* condition performed uniformly well in terms of the Spatial Presence component. We suggest this is due to participants' actions with their real body being accurately reflected by actions in the virtual world, leading to an increased sense of "being there" [41].

Content: The NS for an experience needs reflect the content in the experience. In our specific case, story content was scaffolded onto an exploration task. The goal was for participants to feel immersed and present in the story, not just the sensory experience.

Results from the questionnaires suggest that the *Spatial* condition supported this goal - the natural body movements facilitated users in role playing the character of Laura as she moved around the virtual space. *Spatial*-P15 stated "I had a sense that I, as a whole, got sucked into the virtual world." However, the kind of mapping we present here would likely be unsuitable for other types of virtual experiences, such as those that involve driving or piloting vehicles. In these cases, the real motions used in the *Spatial* condition might negatively impact presence.

Context: In the experience in this study, the dimensions of the virtual world (the pharmacy) matched the dimensions of the space surrounding the participant (the experimental environment). In many experiences, this correspondence may be undesirable or hard to achieve. For example, to simulate a large virtual environment, a one-to-one mapping to a real space is likely impossible. In such a situation, the *Hybrid* condition described in this article may be more appropriate. Beyond this issue, *Spatial* also raises issues of safety and social acceptability. If applied in a large public space would an AR environment distract its users and therefore, potentially, endanger them? And how would non-participants react and relate to those engaged in the experience? These questions are substantially beyond the scope of work in this paper, but serve to highlight how the issue of NS can have broad reaching implications for the design and deployment of a MR experience.

6 Conclusion and Future Work

In this paper, we report on a study of the impact of navigation styles on mixed reality experiences. The results show that using navigation styles with in-world activity favorably impacts measures such as Flow, Presence and Immersion. Additionally, we identify that factors such as context, content and required interactions need to be considered when selecting a navigation style for a MR experience. For example, when deciding to include in-world activity, safety concerns (in real world situations) and ergonomic concerns (when considering longer experiences) should be considered. These concerns highlight the need for further studies in this area, specifically using similar experiences in real world context, varied contents and with a longer duration.

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