PlaneVR: Social Acceptability of Virtual Reality for Aeroplane Passengers

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ABSTRACT

Virtual reality (VR) headsets allow wearers to escape their physical surroundings, immersing themselves in a virtual world. Although escape may not be realistic or acceptable in many everyday situations, air travel is one context where early adoption of VR could be very attractive. While travelling, passengers are seated in restricted spaces for long durations, reliant on limited seat-back displays or mobile devices. This paper explores the social acceptability and usability of VR for in-flight entertainment. In an initial survey, we captured respondents' attitudes towards the social acceptability of VR headsets during air travel. Based on the survey results, we developed a VR in-flight entertainment prototype and evaluated this in a focus group study. Our results discuss methods for improving the acceptability of VR in-flight, including using mixed reality to help users transition between virtual and physical environments and supporting interruption from other co-located people.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; **Empirical studies in HCI**.

KEYWORDS

Virtual Reality, Social Acceptability, In-flight Entertainment

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1 INTRODUCTION

For many of the 3.7 billion air passengers a year [59], air travel means cramped conditions with restricted mobility for durations of up to sixteen hours [61]. Those travelling alone face this monotonous task amongst a group of uncomfortably close strangers, with passengers arranged into ever smaller seats [9]. Entertainment and productivity options are typically limited to personal seat-back displays [24], yet entertainment is crucial to make flying a more tolerable experience. Seat-back displays have significant limitations, including issues of size, viewing angle, brightness, and contrast. Seating and tray-table constraints often make for awkward interactions with these displays. Reclining passengers control the position and angle of the seat-back display, and frequent touch interaction with the screen can be disruptive. Higher fidelity personal displays, such as laptops and other mobile devices offer an increasingly popular alternative [27] but suffer from many of the same limitations. Reclining seats provide little room for laptop screens and meals or refreshments take up the limited tray table space. These limitations make interaction with traditional displays difficult, but present a compelling scenario for VR usage. Current mobile VR systems, like Gear VR [53], depend on space and movement constraints to function well, which closely match the constraints placed on passengers during air travel. This compatibility makes air travel a compelling context for mobile VR.

Air travel is a passenger use case with minimum simulator sickness Nausea and dizziness from using VR, called *simulator sickness*, is caused by a mismatch between visual stimulus and physical motion [33]. VR usage when travelling by car has been shown to induce unacceptable levels of simulator sickness [38] using current hardware. However, VR usage in aeroplane conditions, including turbulence, has been suggested to not cause severe simulator sickness [58]. Plane travel may not require additional motion cues to lower simulator sickness [58], which is the current focus of enabling VR usage during car travel [25, 38, 46]. This advantage means that plane VR use is possible with current hardware without any additional hardware or software interventions to prevent simulator sickness.

Air travel requires passengers to be in relatively confined spaces for extended periods of time The physical constraints of airline seats match the capabilities of mobile VR headsets. Headsets like the Gear VR [53] only include inertial sensing, providing rotational but not positional tracking. Experiences with hardware like this are best when seated, as any positional movement will not be reflected in the field of view. This constraint works well in the limited space available in an aeroplane setting.

Air travel is a context where escaping into a virtual environment could be very desirable People already use a variety of products to provide entertainment, relaxation, and privacy during air travel. The possibility of spending a long flight in a seemingly spacious setting of your own choosing is a compelling application of VR. Early adopters are already enjoying the benefits of in-flight VR using applications designed for home entertainment [62].

Although there are strong arguments for using VR on flights, social barriers may prevent widespread adoption in everyday contexts [56]. For example, passengers might be reluctant to completely

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Figure 1: Mobile VR experiences are currently possible, but social acceptability makes everyday VR use uncomfortable and potentially embarrassing. Left: VR can be comfortably experienced alone at home. Middle: Using VR in a busy public space may attract unwanted attention. Right: Using VR in an aeroplane brings up new questions about social acceptability.

immerse themselves in VR if they will lose their awareness of fellow passengers, the flight crew, safety announcements, and the offering of refreshments/meals. The sustained spectatorship of fellow passengers creates a specific challenge for social acceptability [63], creating a situation where the VR users know they will be observed by a captive audience. Addressing peripheral awareness, social acceptability, and interruption when designing VR entertainment applications is an important step to make VR usable and acceptable during air travel.

This paper explores the social acceptability of using VR for in-flight entertainment through a two-part study, presenting new interaction concepts to address this issue. We completed a survey study to identify user attitudes towards the acceptability of VR usage in-flight and elicit requirements for a VR in-flight entertainment application. Based on the survey results, we developed a VR cinema application designed with features to promote peripheral awareness and allow for interruption. We completed a focus group study using the prototype to gather feedback on our design. Our results provide insights into the design of VR in-flight entertainment applications for a near future where VR is more widely adopted. The key contributions of this paper are:

- Novel survey identifying user attitudes towards the social acceptability of VR usage while travelling by air
- Evaluation of a VR prototype designed for air travel, demonstrating features to improve acceptability by enabling peripheral awareness and interruption in VR
- Discussion of design considerations for creating socially acceptable VR in-flight applications, with broader implications that apply to designing social uses of VR

2 IN-FLIGHT ENTERTAINMENT

2.1 A Brief History

Entertainment has always been a feature of long-distance travel, providing a *"diversion from speed and the risk of the catastrophic accident"* [19]. In-flight entertainment (IFE) is commonly thought to have originated on the Hindenburg airship, where passengers could enjoy piano recitals in a lounge deck [6]. In-flight movie screenings first became a reality in 1961 [20] using shared projected displays. However, passengers were mandated to close their window shades during daytime flights. This led to significant tensions between passengers and staff, with author Alan Levy noting that he was almost assaulted *"merely for lifting a shade to glimpse the Grand Canyon and shedding unwanted light on a fluffy Technicolor marvel starring Sandra Dee"* [19]. Tensions between passengers were eased with the advent of personal headphones and seat-back displays. Modern day seat-back IFE systems can range from 10.4 inches (Economy) to 23+ inches (First class) with noise cancelling headphones and can cost up to \$3 million per plane to install, and \$8 million or more when including content costs [28, 49].

However, the presence of seat-back displays is no-longer a foregone conclusion, with the prior assumption that *"IFE survives because its socioeconomic benefits outweigh its costs"* [48] being questioned. There is a rapidly increasing prevalence of personal devices [54, 55], with up to 90% of passengers bringing a personal screen on board [18]. This rise, coupled with the costs of providing seat-back IFE, has resulted in some airlines opting not to provide seat-back displays [17, 40]. Instead, passengers will have (potentially pay-walled) internet and IFE library access for their personal devices.

2.2 The Importance of In-Flight Entertainment

From the airlines perspective, IFE is necessary because *"entertainment (is) one of the factors that passengers attach greatest importance to when consider(ing) a ticket purchase"* [28]. Indeed, there are suggestions that IFE is secondary in importance only to seating and legroom [3] and one of the primary means of spending time in-flight, outside of relaxing and sleeping [8, 47]. Moreover, passengers have been noted to be *"willing to pay a relatively large amount for enhanced service quality"* resultant from IFE use [10].

For passengers, entertainment is crucial to help pass the time and provide an *"opportunity to imagine themselves somewhere else, anywhere besides thousands of feet above the earth in a metal tube"* [19]. Entertainment acts as *"an intermediary, screening out the fact of flight and the events of travel, (and) is crucial to keeping passengers calm, occupied and content."* [19]. Quality entertainment is a significant factor in the perceived comfort of passengers [3, 47]. For example, when considering the overall comfort of the airline seat, the position and orientation of the screen is comparable with having aisle/space access [57]. IFE systems provide more than comfort, for example aiding *"mental distraction to decrease the psychological* *stress"* of air travel [6], providing guided exercises to decrease the fatigue and health risks involved with air travel [6], reducing fear and anxiety [19], increasing satisfaction and confidence in airlines [37] and inspiring passenger loyalty [35]. Airlines recognise the importance of IFE, which adds value for passengers willing to pay for better services [10] and is a factor considered by passengers when purchasing tickets [28]. There are suggestions that IFE is secondary in importance only to seating and legroom [3].

2.3 Techno-Cocoon: Isolation in Shared, Confined Spaces

The role of IFE has taken on added importance as the seating and cabin design of planes has evolved to accommodate more and more individuals. It has previously been noted that *"a lack of personal space or perceived privacy for seated passengers... elevates the traveller's stress level"* [2] and increases discomfort, with *"space invaders"* [35] a particular concern for aircraft travel. Against this context, IFE can create a greater sense of personal space, having been likened to a *"techno-cocoon"*, offering *"a distraction that makes the cramped conditions of the cabin barely tolerable"* [20]. Headphones in particular have been noted as being *"crucial for sensory privacy and exertion of control"*, acting as *"sensory filters... highlighting the notion of choice and user agency"* [20]. VR has the potential to take this one step further by completely overriding the visual senses, creating a private space for the viewer where an undesirable reality can be completely shut out.

The capability for isolation and immersion is driven by passenger needs [20], and is a primary selling point of first-class cabins where passengers can *"pursue screen-based entertainments without interference from their neighbour or having to interact with anyone else"* [19]. For the economy passenger, it is only effectively bestowed by headphones, which *"create an illusion of sound inside an individual passenger's head, rather than in the shared collective space of the cabin/theater"* [20]. This led [2] to posit that the concept of a cocoon in-flight should be *"taken as inspiration for creating barriers (physical, visual, audio, etc.) that shield passengers against their vulnerabilities"*. However, this demand for isolation is by no means universal, with it being noted that *"while Westerners often like to travel in their own little cocoons, in Asia there is an emerging expectation for more of a 'family and friends' experience"* [20]. More recently, this strong user-driven desire to increase privacy and separation from other air travellers has led to the development of a range of unusual products such as elastic enclosures [36] and pillows [45] that create physical barriers between passengers. The design of the cabin also reflects a desire for privacy, with high seat-backs so *"that passengers can eat their microwaved dinners in silence, watching the flickering screen"* [19]. For those seeking isolation, VR can provide this even in a confined physical space.

2.4 The Problems With Existing IFE

There are, however, common problems when considering IFE. The VR Hyperspace project suggested that passengers are *"least satisfied with the amount and effectiveness of their personal space, and their ability to work"* [15], noting that:

> "Already there are too many screens in the plane with monitors on the seats and passengers bringing on their range of personal devices, e.g. iPads, tablets, kindles. When people are trying to rest it is already difficult with the glare of all these devices. It would be good to focus some work on individual private spaces."

Screen sizes and viewing angles are incomparable with usage in the home or office, being less immersive [14]. Moreover, passengers are not in full control of the position of seat-back displays and personal devices, with the reclining passenger on the next aisle effectively controlling the position/angle of the seat-back display. Reclining seats provide little room for personal devices with larger displays, and meals/refreshments periodically take up the limited tray table space, preventing usage. And the passenger is continually, to a significant degree, aware of the environment of the plane and the activities of those around them, with seat-back displays on economy seats offering few barriers to intrusions by others.

3 VR FOR IN-FLIGHT ENTERTAINMENT

Given the desire for isolation when in-flight and the drawbacks of seat-back IFE and personal devices, there is a strong case to be made for using VR headsets. Passengers are already exploring VR usage in-flight using standard applications [62]. Airlines also recognise the attractiveness of VR, promoting luxury travel experiences by providing headsets in-flight [5, 44], with benefits even being shown regarding safety knowledge transfer regarding how to wear an aircraft life preserver [13]. There have also recently been a number of well-publicised instances of VR headset usage in planes [23, 26, 32]. As The Economist noted: *"VR headsets on planes mean we can isolate ourselves from irritating cabin-mates"* [23].

Previous work has explored in-flight VR by evaluating perception of space and physical constraints. The VR Hyperspace project [11], which finished in 2014 just prior to the advent of low-cost mobile consumer VR headsets such as the Gear VR, aimed to *"enhance the passenger comfort through [...] (the) adoption of Virtual and Mixed Reality technologies in the future air cabin"* [11]. The results of the VR Hyperspace Project provided the first empirical evidence for the feasibility of VR in-flight, demonstrating that VR does not induce unacceptable levels of motion sickness under typical flight movement and turbulence conditions [58], and demonstrating that VR is capable of distracting passengers from sources of discomfort like restricted leg room [34]. However, there is limited research on the requirements, design and usability of VR applications designed with flight in mind.

In-flight VR applications could be greatly improved by incorporating features designed specifically for passenger comfort, which would result in very different applications than those designed for home viewing and maximum immersion. Ahmadpour *et al.* [2] classified passenger attitudes toward their environment into adjusting, avoiding, shielding, and approaching. VR addresses the first three concerns in existing entertainment applications. User control over a virtual environment supports adjusting when content to be positioned optimally based on user comfort, not the position of the seat-back display. VR creates a private virtual space, allowing users to avoid interactions with others. Invasions of space can come from simply *"looking at others or what they are doing"* [35], which is something a VR user can easily control. The shielding of visual and aural senses while using VR also blocks out the undesirable behaviour of other passengers. Ahmadpour also discusses the importance of the social connectedness during travel, and the ability to approach others and engage with passengers and crew members must also be supported [2]. Current VR applications are designed to maximise immersion, and peripheral awareness and interruption are not well supported by current applications VR like Netflix [43]. Research is needed to identify how features designed for air travel can still result in satisfying and immersive VR experiences.

3.1 Social Acceptability and Barriers to VR Adoption

VR Hyperspace suggested that acceptance of illusions, reluctance to be immersed in virtual environments, and privacy are significant barriers to acceptance of VR in-flight [16]. However, we argue that the most significant challenge of using VR in-flight is social acceptance. Recent research has explored the social acceptability of using VR headsets in different contexts such as home, while travelling, and in third places [56] and from different perspectives, including performer and spectator [7].

Social acceptability is an issue when any new technology requires users to engage in highly visible or unusual behaviour in front of others [51]. In the confines of an airline seat, donning a headset and interacting in VR could be uncomfortable for both user and spectator (although the confident VR user is spared from disapproving looks [62]). Passengers may be unwilling to wear a VR headset given concerns about the acceptability of occluding reality and worries about the opinions of other passengers [21]. The anxiety of being immersed in VR in public is a serious barrier to acceptance [29]. Although opinions of acceptability will change over time, early adopters face potentially awkward situations.

Maintaining awareness of others and remaining approachable while in VR are significant issues. Designers of VR in-flight entertainment must consider how VR users can maintain peripheral awareness without breaking the illusion of privacy and immersion created by the virtual environment. Necessary interruptions (e.g. being offered refreshments, letting another passenger pass) must also be detected and conveyed to the VR user. The *"bubble created through media technologies (could) be burst through touch and gesture"* [20], but touch may prove startling during a VR experience. Developing new ways of managing interruption would make VR use more acceptable and comfortable for users and spectators.

4 PLANEVR: DESIGNING VR FOR AIR PASSENGERS

Air travel is an ideal scenario for escaping into VR, but there are social barriers that must be addressed to create acceptable and usable VR travel experiences. We completed a two-part study that identified user attitudes towards VR during travel, elicited design ideas for an in-flight VR entertainment application, and completed a focus group study to evaluate a VR prototype incorporating novel features supporting awareness and interruption.

Figure 2: The survey asks respondents to consider comfort, social acceptability, and interruption for nine scenarios presented using images like these. Left: Using a VR headset while sitting in the aisle seat. Right: Wearing an eyemask while sitting in the window seat. Empty seats are shown to aid survey respondents in understanding which seating position they were to imagine themselves occupying.

4.1 Survey Study: Attitudes to VR for Aeroplane Passengers

Now is a critical time to assess social acceptability because VR headsets are on the cusp of more widespread use, and early adopters are already exploring their use during air travel [62]. There is a need to understand VR use in-flight from both the user's and spectator's perspectives [7, 31], identifying issues of peripheral awareness, social acceptability, interruption, and unintentional disruption.

However, there are obvious ethical and logistical issues involved in performing in-situ study of user behaviours during air travel. Moreover, given the early state of adoption of mobile VR, access to early adopters and passengers that have had some form of experience with VR use in-flight is likely to prove difficult. As such, we designed a survey that could investigate current attitudes to VR use in-flight within the general population to understand the immediate reactions and concerns of the regular airline passengers that may soon encounter VR being used in-flight, or may choose to use their mobile VR headset as a means of IFE. This approach is common in social acceptability research, particularly when technology is not yet ready for real world deployment or ethical issues prevent use in the wild. For example, "imagined situations" in both survey studies (e.g. [51]) and group interviews (e.g. [42]) have been found to elicit valuable results about the social acceptability of gesture-based interaction. VR is similarly difficult to deploy in real world settings at this time e.g. current devices have no emergency shut off. Imagined scenarios provide a first look at social acceptance in this context.

Our survey study provides a novel snapshot of current user attitudes toward VR usage during travel that can inform the design of applications for entertainment and productivity. The survey elicited responses about acceptance of VR, comfort with interruptions while travelling, and how this compares to existing aeroplane activities. The survey presented nine scenarios made from a combination of three seat positions (aisle, middle, and window) and three aeroplane activities (using VR, wearing an eyemask, and using a seat-back display). Each scenario was presented using a description and an image, as shown in Figure 2. The user in each scenario is portrayed in the emergency exit row as a potential baseline for social acceptability. For each of the nine scenarios, respondents were asked seven questions and asked to imagine themselves in different positions. This included two 5-point scale questions about comfort sitting in different positions relative to a VR/Seat-back display user, two 5-point scale questions about acceptability of using VR/Seat-back display in for themselves and others, one 5-point scale question about comfort interrupting a VR/Seat-back display user, and two open ended questions about interruption and social acceptability. The survey also included demographic, air travel, and VR experience questions.

These scenarios were selected to understand how VR usage compares to existing aeroplane activities. The seat-back display is a widely used in-flight device, and gives the spectator a view of the user's current activity. Passengers can easily see others' seat-back displays and can use body language to indicate they are attempting to gain attention. Wearing an eye mask is a similar activity to VR usage because the user's face is obscured and their current activity (e.g. whether they are asleep or awake) is not obvious simply by looking at them. VR similarly obscures the user's face and a spectator has no way of knowing what kind of content they may be viewing. For both VR and eye mask, the user will not be able to see others around them and will be unable to respond to external visual interruptions.

4.2 Survey Results

Respondents were recruited using social media, mailing lists, and other online communities. The results are based on eighty respondents, where respondents completed 73% of the survey on average. 76% of the respondents were male. The respondents ranged in age from 16 to 70, with an average age of 33 (standard deviation 10.8), with 86% of respondents reporting previous experience with VR headsets. Quantitative analysis was completed using non-parametric statistical tests for ordinal data. Where pair-wise comparisons were completed, p values were adjusted using the Bonferroni correction. Open-ended questions were analysed using a qualitative three-stage coding process [60].

4.2.1 Setbacks of Typical Devices. Figure 3 shows the satisfaction ratings for commonly used in-flight devices. For seat-back displays and laptops, satisfaction was relatively low, with just 48% of respondents reporting they were either satisfied or very satisfied. Hand held devices like tablets and smart phones were rated more favourably, with over 70% satisfaction for each. These relatively low levels of satisfaction for laptops and seat-back displays emphasise that there is a need for new approaches to IFE such as VR. The reliance on personal devices, which may be smaller in screen size than the available IFE, also reinforces that there is a demand for personal content and applications.

Respondents described the common shortcomings of their existing devices, for example that seat-back displays are too small, with low quality audio output, are less responsive than a typical smart phone or tablet, and have a poor selection of content available. In some cases, the seat-back displays are also broken or unavailable. One of the only benefits of seat-back displays is that battery life is not an issue. With respect to personal devices, respondents complained about the limited space available, the lack of power, short battery life, lack of privacy, and slow or non-existent WiFi. Other devices like tablets and smart phones had some benefits over seat-back displays and laptops, such as a more compact carrying size, a

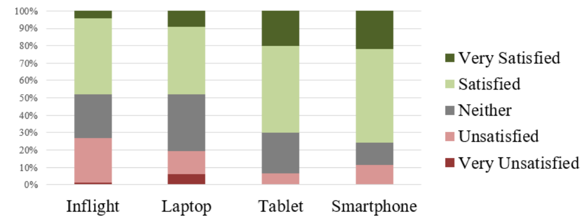

Figure 3: Respondents indicated their overall satisfaction with existing in-flight devices on a five-point scale (Very Satisfied to Very Unsatisfied).

way to keep kids busy, and USB charging capability. However, the small screen on hand held devices make these much less attractive for use on long flights.

4.2.2 Using VR While Travelling. There is a strong interest in using VR during flights, with 75% of respondents indicating they would like to and 15% who already have. Interest in using VR was not without some significant concerns. The biggest issue brought up by respondents was the loss of awareness of others around them and the issues this would cause during flight. The importance of maintaining a general awareness was noted, as described by one respondent as "I would feel vulnerable surrounded by strangers with no way to know who might be approaching or what else is going on" (P27). The most common issue brought up by this lack of awareness was hitting other passengers or invading their space unintentionally. Missing announcements and amenities was also a concern, with one respondent stating that "I would feel a bit cut off from the cabin and what was happening. would they miss me for food and drink as I didn't notice when they came by?" (P60). This common theme suggests that developing features built into VR platforms and/or applications that enable peripheral awareness could mitigate these concerns. Respondents also mentioned more general issues of feeling rude for putting on a headset, looking silly and inconspicuous during use, and annoying other passengers. Some of these issues may become less of a concern when VR headsets become more common and social norms and standards for VR use are developed. Motion sickness was also brought up as a potential issue. However, previous work indicates the flight movement and turbulence does not cause severe motion sickness while using VR [58], but users without experience using VR in this context may still be concerned.

4.2.3 Acceptance of VR Around the Cabin. We asked respondents how acceptable they found different activities based on where people were sitting in the cabin. Figure 4 shows the acceptability ratings for the nine scenarios presented in the survey. The Friedman test shows there are significant differences between the acceptability of using a seat-back display, eyemask, and VR headset ($p < 0.0001$, $n=56$ when incomplete responses were excluded). Pairwise comparisons between these conditions using the Wilcoxon Signed Rank test show significant differences between all conditions (Seat-back/Eyemask, $p < 0.0001$, Eyemask/VR, $p < 0.0001$, Seat-back/VR, $p < 0.0001$). Critical values for all tested included a Bonferroni correction where p must be less than 0.017 to be significant. The results show that VR usage was rated as significantly less acceptable than using a

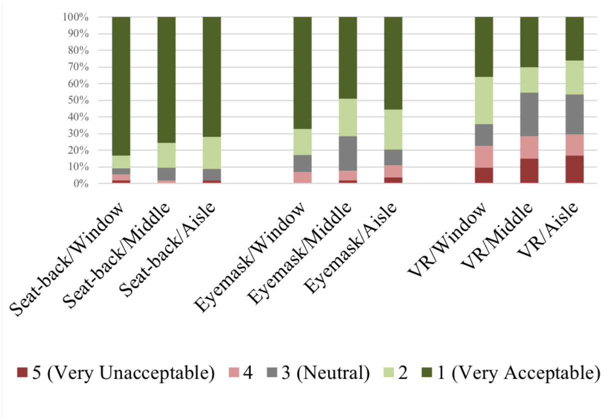

Figure 4: Respondents indicated the acceptability of three activities (using seat-back display, wearing an eyemask, using VR headset) when seated in the window, middle, or aisle seat on a five-point scale (Very Unacceptable to Very Acceptable).

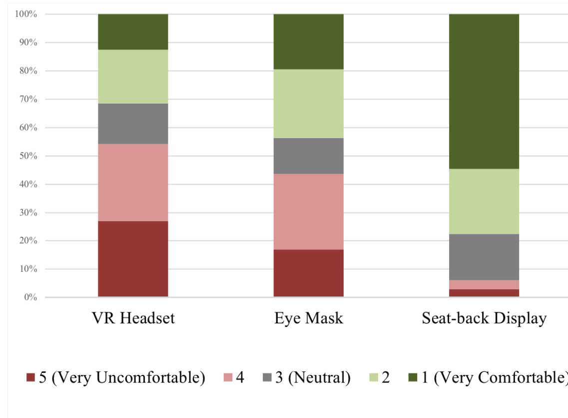

Figure 5: Respondents indications their comfort level with interrupting another passenger during different activities on a five-point scale (Very Uncomfortable to Very Comfortable).

seat-back display and wearing an eyemask. Although we designed the survey to include the eyemask because of its similarity to using VR, respondents pointed out that sleeping was a necessary human activity and thus needed to be tolerated. Respondents also noted that where a passenger was sitting changed their ideas about what is acceptable or not. For example, one respondent stated that "in both the eyemask and VR cases, I feel like this is the ideal window seat person to have next to me. They are not going to bother me. I can pretend they don't exist" (P52). Other respondents said this would be a "waste" of the window seat as the person "should enjoy the real life spectacle of flight at the window seat" (P42). These responses hint at the early tensions of IFE between the passengers that wished to adopt new entertainment technologies and those that felt it impeded their own experience in-flight. When considering a VR user in the aisle seat, respondents agreed that those sitting in the aisle are responsible for letting others in the row get up, which might be difficult if they were using a VR headset.

4.2.4 Interruption and Space Invasion. Figure 5 shows the comfort levels of interrupting fellow passengers based on activity. The Friedman test shows there are significant differences between comfort of interrupting people using a seat-back display, wearing an eyemask, and using a VR headset ($p < 0.0001$, n=56 when incomplete responses excluded). Pairwise comparisons using the Wilcoxon Signed Rank test show significant differences between all conditions (Seat-back/Eyemask, $p < 0.0004$, Eyemask/VR, $p < 0.0006$, Seat-back/VR, $p < 0.0001$). Critical values for all tested included a Bonferroni correction where p must be less than 0.017 to be significant. Respondents described how they would prefer to interrupt people involved in these different activities. When using a seat-back display, interruption is straightforward by speaking to the person, waving at them, or gently nudging them to get attention. Interrupting someone wearing an eyemask might require more intrusive actions, waking them with a loud speech or direct touch, explaining the increased discomfort with interruption. Interrupting a VR user was even more uncomfortable, with one participant realising that "I'd have to touch the person whenever I need their attention. That makes me most uncomfortable. Touching strangers - invading their personal space - is awkward." (P63). Another respondent noted that they would not know when was a good time to interrupt a VR user, commenting that "the HMD combines the issues with occluded view with the issues of being unsure of the passenger's availability since we don't know if they are watching a movie, deep in some entertainment, or possibly even still able to see you" (P59). However, one respondent noted that sleeping passengers could be unpleasant, commenting that "the person in VR won't potentially fall on top of me whilst sleeping and not notice. The VR person is awake and aware of her body movements" (P63).

4.3 Summary

Our survey reinforces the limitations of current options for IFE and the dissatisfaction felt by passengers. However, whilst VR has much potential for improving entertainment options, the survey also demonstrates that VR is currently perceived as significantly less acceptable than existing in-flight activities, with concerns regarding awareness of other passengers and interruptions particularly prevalent. While some issues of social acceptability require social and cultural change, we would suggest that many of the issues brought up by respondents can be solved through interaction design. Based on the survey, we identified three key concepts which we used to develop a software intervention to improve the social acceptability for an in-flight VR entertainment application:

- VR should provide awareness of the events/surroundings of the plane, whilst preserving immersion and isolation.
- Interaction must not require extensive head or hand movements, as unintentional contact with other passengers would be unacceptable.
- Interruption needs to be supported in ways that are not abrupt for the VR user and acceptable for fellow passengers and staff to perform

5 FOCUS GROUP STUDY: PROTOTYPING VR SOLUTIONS

The focus group study utilised a prototype of a VR in-flight entertainment application. Given the safety and logistical issues of running an evaluation in real air travel contexts, a focus group provides an ideal setting to gain feedback on the novel features of the application at this relatively early stage of development. The results provide a basis for deploying these features in real-world VR applications.

5.1 PlaneVR: Prototype for In-Flight Entertainment

PlaneVR was designed for entertainment as this is one of the most common activities to pass the time while travelling. Using PlaneVR, users can watch video content in a virtual home theatre designed to be spacious and relaxing. We chose a home theatre application for three reasons. Firstly, this setting overcomes display size dissatisfaction by simulating a large cinema screen and creates the illusion of greater personal space. As a distraction during travel, a home theatre is an attractive escape. Secondly, a simulated screen allows users to enjoy VR content without excessive movement since content is displayed in front of the user, as opposed to 360 degree content displayed around the user. Finally, this kind of home entertainment setting is popular in existing VR applications and is likely to be familiar to users with previous experience of VR. Applications such as the Oculus home theatre and Netflix for Gear VR both use similar environments designed for extended content viewing in VR. As an established context for prolonged VR entertainment, a home theatre application is ideal for testing new interruptions and awareness techniques.

The setting, as shown in Figure 6, is a wood panelled room with soft furnishings, decorations, and large windows. The point of view (Figure 6, bottom) is rendered from the couch position in the centre of the room. The exterior includes a sunset view which can be seen through the windows on either side of the room. A large television display is placed in front of the user. The lighting in the room automatically dims when media playback begins. The application includes four key features that have been developed to address the needs identified in the survey:

Mirror The environment includes two large mirrors on either side of the display. When the user directs their gaze to either of these mirrors, it will display the view from outside of the VR headset using a camera at the front of the headset. This window allows a user to quickly look up from their media and glimpse the outside world without removing the headset.

Peek If a larger view of the outside world is desired, users can toggle away the home theatre view and see only the view from a camera at the front of the headset. This is rendered as a large canvas in front of the user, allowing them to quickly step out of the virtual environment without removing the headset.

Doorbell To allow people to interrupt the VR user, the doorbell feature displayed a visual prompt in VR when an external button was pushed, enabling fellow passengers to gain the VR user's attention without physically invading their space.

Push If a more direct interruption is needed, the push feature allowed people to interrupt the VR user. Push switches the virtual environment to the forward-facing camera view when an external button is pushed. This forces the VR user to attend to the outside world immediately when triggered.

Figure 6: Complete view of home theatre setting. Large windows at each side create a spacious environment. The mirrors on each side of the display can be used to peek outside of the headset using the forward-facing camera.

5.2 Hardware: Gear VR

The application was developed for Samsung Gear VR [53], which uses a mobile phone and headset to create a mobile VR experience. The Gear VR headset uses rotational tracking to update the field of view when a user moves their head. The right-hand side of the headset incorporates a touch pad and four buttons for user input. While wearing the headset, gaze can also be used for input. The headset can be paired with a hand held Bluetooth controller with a touch-pad, buttons, and rotational tracking for raycasting input.

Our study utilised a 2017 Gear VR headset with controller and a Samsung S7 phone. The headset weighs 345 grams and supports of 101° field of view. The application used only standard sensors and no additional hardware was required to run the application. The mirror and peek, and push features were implemented using the main camera on the mobile phone, which faces forward when mounted in the headset. The doorbell and push features were activated using buttons on the hand held controller. Peek was activated using a button on the VR headset. All input was designed considering the limited physical space available to users in aeroplanes. User actions are performed with small head movements or button presses on the headset. Spectator actions use the external buttons that do not require physical contact with the user.

5.3 Focus Group Results

The results are based on three hour-long focus groups of four people each for a total of twelve participants. Participants ranged in age from twenty-three to thirty-six with an average age of twenty-eight (standard deviation 4.2), with seven men and five women. Eight participants had prior experience with VR. Each focus group began with a short questionnaire. Participants then experienced a demonstration of PlaneVR and tried the four features of the prototype. The participants then took part in a semi-structured group interview. The analysis is based on a quantitative analysis of the questionnaires and a qualitative analysis of the transcripts using a three-stage coding process [60].

5.3.1 Travelling and Socialising with VR. The constant presence of others is one of the biggest issues with using VR while travelling. Being a spectator is potentially more awkward, a sentiment echoed by people who have already experimented with VR during their own travels [62]. One participant stated that *"When you're in there, you don't pay any attention. I felt less weird being in it than I did being silent while watching everybody else do it"* (P3-4). The VR headset creates an effective barrier between you and other passengers, blocking communication and awareness in both directions. One participant stated that *"I think I'd quite like to know if they were using the camera or not. Because that's a bit weird. You think they're watching something and they're actually just watching you"* (P3-4). Being able to see the visibility of system status as a spectator is an important feature of acceptable interactions [42]. This is the same kind of issue which made Google Glass so undesirable [21], but could be addressed when designing VR for social a public contexts.

Participants also discussed how VR could become more acceptable over time, especially if hardware was provided by airlines. Even over the short period of a flight, participants felt they could grow comfortable using a headset. One participant stated that *"when you've become more comfortable in your environment then I'd feel more comfortable to use a headset because everyone is just more settled"* (P2-3).

Travelling with friends or family changes what is expected of passengers during a flight. Our results are in line with previous work that suggests VR headsets are less socially acceptable in settings where social interaction is expected [56]. One participant stated that *"I don't mind if the stranger is trying to exclude me. They're just trying to pass the time. Whereas, if someone I'm with is excluding me then that's quite a turn-off [. . .] I'd be bored on the flight as well. We should be bored together"* (P2-4). The *"shared boredom"* of travelling together inspires the possibility of shared VR experiences. Previous work has demonstrated the joy of shared media viewing in virtual environments for distant viewers [39], but the same approach could be used with co-located passengers. This would support the social activities travellers often engage in, for example *"if there's a couple of you watching the same film or even different films [. . .] You've both got your own screen and you can chat about it"* (P2-4). Virtual hangout spaces such as Rec Room [1] and Altspace [41] show how social interaction can be facilitated through VR. Creating social spaces when VR users are co-located could provide a new kind of escape while travelling.

5.3.2 Controlling Your Flight Experience. The lack of control and inability to adjust your surroundings is a major source of discomfort while travelling [4]. Participants discussed the power of using VR to control your virtual environment and the importance of controlling how and when you can be interrupted. The ability to adjust everything from the position of the mirrors, the interior decorations, the design of the setting, and the entertainment content available was identified as a major strength of the virtual environment. Although our prototype did not support customisation, the ability to do this within the virtual environment was desired as one's mood can change frequently while travelling. This raises questions about how to support this using the limited input techniques available with current mobile VR devices and the limited space available in a typical airline seat. Previous work has looked at different mobile input techniques such as touching the front of a head mounted display [22], but more research is needed to understand how to incorporate additional modalities and achieve better control when manipulating virtual objects.

When discussing the doorbell and push features, participants were concerned about who would have access to these and how they might be used. One participant stated that *"I feel like, the one that switches automatically [push], I would want reserved for like, aeroplane safety stuff. But the getting your attention [doorbell], I wouldn't have a problem with your friends having it or your partner having it or the steward having it just for drinks or whatever"* (P3-3). The push feature was seen as something that could clearly be used by flight crew for safety purposes and important announcements, similar to the pause screen common to current IFE systems. However, passing control to fellow passengers was less desirable, and the push feature was deemed too disruptive in this case. Participants were also concerned about the misuse of the interruption features like doorbell, and push, where other passengers might prove to be a nuisance when the user is seeking isolation.

This inability to see everyday social cues while wearing a headset makes interruption by other passengers more awkward. For example, one participant noted that *"I think if you're on an aeroplane and somebody's reading a book and you want to get out, you'd sort of shift in a way that suggests that you want to get up and then they might notice that, at which point you can gauge them"* (P1-2). New methods of getting attention may need to be developed if headsets become more widely used during air travel. The doorbell feature was discussed positively when used for passenger interruptions. One participant suggested that *"I think if a stranger did say to me 'here have this, please use it if you want to get up.' I'd be like, OK. They're clearly OK with this."* (P1-2). Additionally, participants were positive that if they needed to interrupt a fellow passenger, they would be happy to use the doorbell feature.

5.3.3 Uncomfortable Interruptions. VR users may lose awareness of the people around them, invading others' spaces or being uncomfortably surprised when others invade their own space. One participant was concerned that VR games they have seen would not be suitable in an aeroplane, stating that *"if someone is playing a game, they will be crazy and they will wave their hands, arms, something like that"* (P2-1). While such interaction might be exciting in a home setting, it highlights the need for travel applications to be designed differently. The most uncomfortable interruption discussed by participants was being touched or tapped while in VR, which would break immersion and potentially frighten the user. One participant stated that *"I think someone tapping you could really take you out of that, In a sort of unsettling way"* (P1-3). Participants discussed how this could be especially frightening if a user was watching a scary movie, for example *"you could be watching a scary thing and then someone taps you. you might hit them."* (P1-1). The confirms the survey results that tapping and other physical interruptions would not be acceptable for VR users.

5.3.4 Wearing a VR Headset Continuously. Putting on and taking off the headset requires a small amount of effort, and participants expressed a desire to wear the headset continuously where possible. For example, one participant stated that *"there's no real issue with the logistics of having to place the device properly to get proper viewing angles and stuff like that or having to constantly readjust hopefully. I mean once the headset's on, it's on."* (P1-3).

Participants discussed how the mirror feature made it more acceptable and comfortable to wear the headset for extended periods of time because they could maintain a general awareness of what was going on outside of the virtual environment. One participant stated that *"I think the mirror thing is quite good. To just quickly check what's going on without turning the video off, you can just have a quick look and see what's happening"* (P3-1). Another participant stated that *"You don't have that unknown of what actually is going on around you. You can check that there's nothing malicious going on in the real world"* (P3-3). The ability to periodically check your surroundings, the same way you might look up from a book, gave users a greater sense of comfort. The mirror supports this without forcing the user to leave the virtual environment or disrupt their entertainment activity.

Many passengers seek isolation in a "techno-cocoon" during travel, but participants recognised that total immersion isn't feasible or acceptable during air travel. One participant noted that PlaneVR made it possible to stay immersed while still being approachable, stating that *"it would feel good knowing that I could quite easily get out, you know, switch out without having to stop or take the headset off."* (P2-3).

The peek feature also had the unexpected benefit of allowing users to perform short tasks in the "real world" without removing the headset. For example, participants described how using peek would enable them to grab items from the seat-back pocket or take a drink. For frequent tasks, removing the headset might be cumbersome. The ability to perform such tasks without removing the headset makes it easier to enjoy VR without disrupting normal aeroplane activities.

5.3.5 Moving between the Virtual and the Real. Participants recognised there were some situations where removing the headset would be necessary, for example when a fellow passenger or crew member needed attention. One participant stated that *"if somebody's getting your attention then it's almost certain that you are going to remove the device in the end. [. . .] You're not gonna have a conversation with them or face them with it"* (P2-3). Although participants agreed that any direct interaction would probably require removing the headset, one group discussed how unusual but feasible it would be to carry on a conversation while wearing the headset, and how odd this might look to a spectator or conversation partner.

Participants discussed how the peek and knock features make it easier to tell if your attention is needed. This creates an interesting period where one is still in VR but beginning to remove themselves into the real world. This transition period could be jarring without the peek feature, which gives the user a chance to check their physical surroundings before removing the headset. One participant stated that *"you can't just rip the [headset] off, you know. [. . .] it would be quite good if as you're in the process of starting to take it off you can quickly see who you're dealing with and then you start taking it off to then actually converse with them"* (P2-3). The ability to make a smoother re-entry into reality and under your own terms was an unexpected benefit of the peek feature. This is not dissimilar to the process of moving your things when someone needs to get past you, which is an implicit way to express yourself by acting friendly, indifferent, or unhappy.

6 DISCUSSION

Through an online survey we identified the key challenges facing VR adoption in-flight: providing awareness of others in the cabin and pertinent events (e.g. cabin crew and safety announcements) and facilitating necessary interruption by fellow passengers and staff. We completed a focus group study using a VR IFE prototype to explore how awareness could be provided to VR-using passengers through peripheral augmented reality (AR) elements embedded in the virtual environment. We also explored how interruptions could be enacted in ways that were acceptable to those being interrupted and those necessitating the interruption.

This research captures user attitudes towards the acceptability of in-flight VR usage at an interesting period in VR's history when high-fidelity mobile headsets have become a readily available commercial product. The features we evaluated provide a basis for enhancing peripheral awareness and enabling interruption for VR use while travelling. These results are also useful in contexts beyond air travel, with implications for VR applications designed for any public or social settings. As social norms and standards for VR usage evolve, developers and designers have a unique opportunity to create applications that will change the perception of VR as a solitary technology to one that is usable in public and social settings.

6.1 Exploring the Space Between Reality and VR

Regarding awareness, the most successful feature that we developed used the main phone camera to show the outside world within the virtual environment. The experience of exiting VR can be uncomfortable , but methods that extend the VR experience can ease this transition [30]. This hybrid VR/AR feature created a space between reality and virtual reality that made it more comfortable for users to transition between these spaces. Implementing AR features using cameras and other sensors allows VR users to maintain peripheral awareness while in VR and to prepare themselves when exiting VR. Such features should be readily accessible from within virtual environments using continuous inputs like gaze and discrete inputs like button presses.

In Oculus apps, there is a feature called the "pass through" view but is only accessible from specific menus and is not part of the developer's API. Windows Mixed Reality Headsets provide a "flashlight" for showing a part of the front-facing camera feed located around a controller. And headsets like the HTC Vive also include a forward-facing camera, but features like boundary warnings using this are not enabled by default. However, wider use of this feature could greatly improve the usability of VR applications. The hybrid spaces we created using the camera view bridged the virtual and physical environments. This transition space elicited a variety of potential uses by the focus groups, such as continually present monitoring, offering periodic re-assurance, and creating a space to prepare yourself when removing the VR headset.

VR can be uncomfortable to use in social settings because spectators have limited visibility of the users' experience. Improving spectator experiences by giving spectators good visibility of users' actions and the resulting effects [50] can improve to social acceptability of new interaction techniques [42]. Developers are already exploring new techniques for bridging VR content with user's immediate surroundings and providing output for spectators [12], but more work is needed. If public VR use is going to become a reality, headsets must start to incorporate outputs geared towards spectators so that VR users are not completely isolated. Our participants discussed how simple outputs such as lights indicating if the phone's camera was in use could put them at ease about what the VR user is experiencing. Cues about interruptability could also provide spectators with a better understanding of a VR user's state, for example to determine when to interrupt a VR user. Such visual outputs could be easily incorporated into headset design, giving VR a greater appeal in a wider variety of contexts.

6.2 Interruption and Disruption

Interruption within software that allows spectators to gain the attention of VR users without direct physical contact and gives VR users options for how to control how and when they can be interrupted. Supporting better interruption and easing concerns of spectators requires some visibility of system status aimed at spectators, and inputs designed for spectators such as external sensors and buttons.

Participant concerns about interruption were rooted firmly in ensuring that the right level of interruption was used for a given scenario, whilst preventing abuse by, and annoyance from, fellow passengers. The doorbell approach would appear particularly promising as an acceptable means of notifying the VR user that their attention is needed. HTC Vive currently includes a "knock" feature for spectators aware of how to access the feature, but mobile headsets have no obvious software interruptions available, forcing spectators to resort to physical touch to gain attention. If the only buttons available are incorporated into the headset, this could be a difficult situation for a spectator. An unwanted touch to a headset can be uncomfortable for a VR user [22], so external methods of interruption are needed if VR is going to leave the living room.

Although current mobile headsets include limited sensing and output capabilities, adding additional features could enhance the social acceptability of public and social VR use. Capabilities such as bi-directional awareness, exploiting additional sensing such as wide-angle cameras, and using existing in-flight systems as a bridge between user and fellow passengers all warrant further exploration. For example, the in-built hardware was not well suited to capturing and streaming external audio, but including this audio feed with the mirror, peek, and push features would add another dimension to peripheral awareness. Headsets with sufficient capability for social signal processing present compelling scenarios, for example by reacting to a spoken phrase such as "excuse me" to enact a more natural interruption.

6.3 Methods for Near Futures

It is inherently challenging designing for a social context that does not yet exist [52], in this case designing for a possible future where VR use is more widespread. A critical reflection on external validity for this work means looking forward to the *projective validity* [52]: do our results hold true as VR headsets become widely adopted? For example, do VR headsets which make use of forward facing cameras and "pass through" views prove more popular and acceptable than those without?

With respect to our survey and the focus group study, the ecological validity is constrained by the degree to which we were removed from in-situ evaluations. For the survey, we asked participants to imagine themselves in the contexts described. Using imagined scenarios provided rich data on attitudes to adoption, usage and experience of VR in-flight and offered the greatest possibility of extracting novel and useful insights. In the focus group, we used the social group setting to explore the social features of our IFE prototype. Surveys and focus groups like these are often used to evaluation the social acceptability of new technologies [31, 42, 51, 56]. Other approaches could have been pursued, for example in-situ evaluation with real passengers or laboratory studies that mimicked a plane interior. However, we would suggest that such approaches do not offer the best value at this early stage. Through focus groups, we were able to more broadly explore the problems identified in the survey, and potential solutions offered, providing us with a breadth of new insight into awareness in IFE. We would suggest further iteration along a similar methodology is required at this stage given the cost and difficulty (e.g. ethics, safety, legality) of in-situ evaluations in-flight. However, we argue that the results provided by these methods valuable insights that will help shape the adoption of VR into new social contexts.

7 CONCLUSION

This paper presents a two-part survey and focus group study that provides design recommendations for the development of mobile VR entertainment applications that are socially acceptable for use when travelling by air. Our initial survey study highlighted current shortfalls of entertainment devices and attitudes towards VR usage in an aeroplane setting. The survey gave us three design directions for an in-flight entertainment application; to reduce movement required to interact in VR, the give users in VR peripheral awareness of their physical environment, and to enable interruption without requiring any physical contact. We created a prototype with features based on these ideas and evaluated this in a focus group study. The results provide insights into designing VR with hybrid AR/VR spaces to bridge the gap between reality and virtual reality and ways of supporting interruption and spectator experience. By creating applications suitable for social use, VR could move out of the living room into more public and social settings.

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