Enacting Asymmetric Passenger Experiences Using Disparate Immersive Devices in Transit

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Immersive technologies allow us to personalize our reality while traveling; however, widespread adoption remains limited. This study investigates the challenges of adopting immersive devices in transit, particularly when passengers encounter *asymmetric experiences* using disparate devices. These situations arise as co-located passengers adopt devices with varying levels of immersion, environmental information, and interactive capabilities. Using an enactment methodology in a transit scenario involving disparate devices, our study (N=21) reveals that asymmetric passenger experiences create a sense of disconnection among passengers, especially with varying device immersion capabilities. When interactions require more than a basic response, for example complex verbal exchanges relying on social cues like gaze, adoption is further hindered. The incorporation of cues from reality addresses safety concerns but requires further refinement to support interactions that require complex or extended user involvement. This research advances the understanding of asymmetric passenger dynamics, contributing to the design of immersive technologies for transit settings.

CCS CONCEPTS • **Human-centered computing → Mixed / augmented reality; • Human-centered computing → User studies**

Additional Keywords and Phrases: Immersive technology, Asymmetric experiences, Public transport, Passengers, Enactments

1 INTRODUCTION

Immersive technologies enable us to shape our reality, creating opportunities to reclaim the time we spend traveling. Advancements in immersive technologies, exemplified by the recent Apple Vision Pro release [133], signify growing interest in the industry and the increasing possibility of these technologies in everyday life. As more users adopt immersive technologies, we move towards a near future in transit settings where passengers use a range of disparate immersive devices. This results in *asymmetric co-located experiences,* where passengers may encounter *unexpected interactions* with each other whilst using devices with different immersive capabilities or attending to different tasks. For instance, this might involve navigating around another passenger in close proximity or asking or responding to a question from someone nearby unexpectedly. This new passenger experience dynamic raises challenges unique to transit settings, such as awareness of surroundings (e.g., getting off at the right stop) or switching between virtuality and reality (e.g., to talk to fellow passengers). This work explores these social immersive interaction challenges using an enactment method for future asymmetric passenger scenarios.

Currently, a typical passenger scenario involves using travel time for productivity [40] or entertainment [41] with devices such as phones or laptops. However, immersive technologies offer unique advantages over

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traditional devices, such as the ability to render virtual content around the user. This allows passengers to disengage from uncomfortable interactions with other passengers [113] and the constraints of confined spaces [97]. While the wider adoption of immersive technologies still faces challenges related to privacy [1], safety [8], and social acceptability [79], considerable efforts to improve usability and acceptance have been made in industry and academia. Approaches to improving safety and social acceptability include integrating an external view as part of the immersive experience [121] or embedding key real-world cues into virtual environments [10]. The early adoption of headsets on planes [134, 135] and solutions designed for more private in-car experiences [136] also demonstrate the growing interest in these technologies. Although not yet fully adapted to the dynamic nature of transit environments, it is anticipated that immersive technologies will continue to evolve for wider use in public spaces, including public transport.

As immersive technologies become common, we will increasingly experience asymmetrical experiences in transit settings. These experiences occur when multiple co-located users are using devices with varying levels of immersion, environmental information, and interactive abilities. For example, consider the contrast between a mobile phone and a virtual reality (VR) headset for interacting with virtual content. Prior research has identified challenges in asymmetric experiences, including difficulties in user interactions [19, 44, 45, 76], behavioral influence [122], power imbalances [127], and social exclusion [56]. However, these studies predominantly examined asymmetric experiences in collaborative tasks. In contrast, the asymmetric passenger experiences we examine do not revolve around collaboration, but focus on the co-located experiences of passengers in small spaces who are not collaborating but may need to unexpectedly interact while in transit. Transit settings, particularly in ground transportation, present unique challenges characterized by constantly changing passengers and external environments [10], leading to the occurrence of unexpected interactions.

To understand the dynamics and challenges of asymmetric passenger experiences in future transit scenarios, we used an enactment method. Enactments are a powerful technique that enables us to explore and speculate on contexts that do not yet exist [102]. We recreated a train transit scenario with three levels of asymmetric user experiences: one participant using a mobile phone, another with a commercially available VR headset, and the third equipped with a VR headset that includes real-time passenger body tracking and environmental cues. Participants were able to experience and interact with one another in a simulated environment, mirroring real-world transit conditions and engaging in asymmetric experiences.

We found that interactions requiring active user involvement, e.g., engaging in a back-and-forth conversation, are perceived as least acceptable when immersive technologies are in use. Particularly complex dynamics are observed in verbal interactions that depend on gaze for assessment, initiation, and response. The asymmetry in passengers' experiences creates a sense of disconnection, resulting in interaction challenges, most evident between users at the opposing ends of the reality/virtuality continuum [87], such as between VR users and phone users. Furthermore, integrating reality cues, referred to as *Reality Anchors* [10], into the immersive setup mitigates physical safety concerns associated with passenger interactions and reassures users about nearby passengers' movements. However, these anchors require additional detail to support interactions that require complex or extended user involvement. In our work we simulated a mixture of reality and virtuality in a VR headset, with the goal that these results would apply to a broad range of future devices across the reality/virtuality continuum. As immersive devices become more dynamic and the boundaries between reality and virtuality become more fluid, our findings around social issues such as disconnection and interaction difficulty remain relevant.

This study represents an important first step toward understanding the dynamics of asymmetric passenger experiences in transit. This speculative work enables refinements to the design of such experiences, critical for the adoption of immersive technologies in real-world settings. These refinements are essential to support the near future of transit settings characterized by asymmetric experiences. While current advancements in immersive technologies have begun addressing safety, comfort, and social acceptability, they need to go beyond these concerns. Addressing the asymmetric complexities of passenger interactions and social connectivity, such as enabling genuine engagement with reality and facilitating conversations, is essential. This paper makes the following contributions:

1. We investigate asymmetric passenger experiences through novel enactments of a future transit scenario;
2. We demonstrate that engagement levels (passive, active, reactive) and interaction nature (verbal, non-verbal) significantly influence immersive technology acceptance in transit;
3. We examine how asymmetric experiences can lead to disconnection, posing interaction challenges, particularly for users at reality/virtuality extremes;
4. We evaluate the integration of cues from reality in asymmetric scenarios, finding that immersive tracking mitigates physical safety concerns associated with passenger interactions. However, our findings also highlight the need for additional cues to facilitate passenger interactions.

2 RELATED WORK

2.1 Key Concepts for This Work

While terms such as Mixed Reality (MR) [107] and Extended Reality (XR) [96] are commonly used in the HCI community to refer to technologies across the reality/virtuality continuum [87], this paper uses the term *Immersive Technologie*s to encompass devices that can dynamically shift between reality and virtuality. In this work, we utilized Virtual Reality headsets to present a mix of reality and virtuality content, aiming to simulate a near future where devices can easily adapt to user needs by seamlessly integrating real and virtual elements. Additionally, we included personas of users of different technologies, such as mobile phones and VR headsets, to represent a range of devices across the continuum. This approach ensures that our findings will be applicable to various immersive devices, avoiding the limitations of current definitions and separations of these technologies.

Given the evolving terminology and the potential for terms to have distinct meanings between different communities, it is important to clarify the specific concepts used in this paper. To avoid ambiguity, below are the key definitions for other key concepts used in this work:

- Asymmetric experiences: Co-located passenger experiences that emerge when individuals simultaneously engage with devices featuring varying levels of immersion, environmental information, and interactive capabilities. Inspired by prior work on asymmetric co-located experiences (e.g., [44, 128]), this work uses the term to describe experiences that occur in a co-located, non-collaborative setting. An example is co-located passengers simultaneously using a mobile phone and a VR headset.
- Unexpected interactions: Passenger interactions that occur unpredictably while individuals are using disparate devices with varying capabilities to support those interactions. Similar to prior work on unexpected interruptions [36], which are unplanned and occur while users are engaged in other activities, unexpected interactions might involve an unplanned need to navigate around another

passenger in close proximity or an unexpected need to ask or respond to a question from someone nearby.

- 'Reality Anchors': Introduced in prior work [10], these are reference points from reality, such as other passengers or internal furniture, positioned within a virtual environment. These anchors help maintain awareness of the real environment, improving perceived safety, social acceptability, and comfort while sustaining immersion (discussed in more detail in Section 3.4.4).

2.2 Asymmetry Dynamics in Immersive Technology Contexts

Asymmetric experiences among co-located individuals can vary by user roles, locations, or devices [56]. We specifically address asymmetric experiences that emerge when individuals simultaneously engage with devices featuring varying levels of immersion, environmental information, and interactive capabilities, such as co-located users using a mobile phone and a VR headset simultaneously. Previous work has categorized device-based asymmetric experiences into three levels of asymmetry: low (allowing direct interaction between users' environments), medium (involving indirect interaction between users' environments), and high (no direct link between user environments, necessitating alternative modalities such as verbal communication) [6]. High-level asymmetry often leads to intricate dynamics, positioning users at opposite ends of the reality/virtuality spectrum [87].

While some have explored medium asymmetry scenarios, such as collaborations between AR and VR users [39], most past work explores asymmetry in interactions between co-located individuals wearing head-mounted displays (HMD) and those without HMDs, demonstrating effects on user behaviors, including personal space and social signals [122]. Moreover, high levels of asymmetry can lead to power imbalances between unaware users and fully aware bystanders [95], with the evolving capabilities of HMDs potentially introducing new scenarios where these power imbalances may undergo changes in dynamics. Additionally, it is unclear how asymmetric experiences, which can result in social exclusion among co-located users [56], can impact interactions between users with varying levels of information.

Prior efforts to bridge this gap in user experiences with asymmetry have primarily focused on addressing the interaction breakdown from a non-HMD user perspective, particularly in collaborative scenarios [19, 29, 44, 45, 75, 76, 108, 126]. Example solutions include providing the view of the HMD user's face [19, 76], to reintroduce the missing social cues, such as gaze and facial expression, highlighting the important role of nonverbal communication [14, 64, 91], often disrupted by immersive technologies. Other solutions focus on sharing the virtual environment to facilitate connection between users, which can take the form of wearables [19, 45, 76], portable devices [126], projections [44] table-top displays [75, 108], non-screen-based interfaces [57] or a combination of methods [128]. Others examined addressing the interaction gap in a bi-directional manner, creating multi-environments, presenting views differently for HMD and non-HMD users [55], or adjusting the environment based on the user's role and capabilities [72]. Work focused on the HMD user's perspective has primarily aimed at enhancing the user's awareness of bystanders or passersby through visualizations or notifications [84, 123], discussed in more detail in Section 2.3.1.

In particular, it remains uncertain whether asymmetric experiences present similar or distinct challenges in transit settings, where interactions are often spontaneous, and co-located passengers frequently change, or how the degree of asymmetry influences interactions between passengers.

2.3 Open Challenges of Using Immersive Devices in Transit

Recent statistical data in England shows the prevalence of public transportation usage, with an average of 757 trips per person [137]. Immersive technologies could allow us to customize our reality on these trips, offering the means to disengage from uncomfortable interactions with fellow passengers [113], circumvent the constraints of confined spaces [97], or repurpose travel time for productivity [40] or entertainment [41]. Early adopters have explored the use of immersive devices during air travel [134, 135, 138] and there have been developments in commercial applications tailored for in-flight [139] and in-car experiences [136, 140]. Moreover, the latest release of Apple Vision Pro [133] notably promotes the use of immersive devices during flight, marking a significant move towards their adoption in transit environments. Given the continuous advancement of immersive devices [133, 141, 142], an increased adoption in transit settings is a foreseeable future trend. Nevertheless, concerns regarding awareness, privacy, social acceptability, and safety persist as significant factors shaping the medium-term future of asymmetric experiences.

2.3.1 Reality Awareness in Dynamic Environments

The limited environmental awareness when engaging with immersive devices represents a significant barrier to their widespread adoption. This issue is pronounced in transit settings, where unique awareness concerns emerge, such as lack of awareness of one's belongings [8], surrounding furniture [103], missing a stop [71], important announcements [121], or personal safety [8, 10]. Shorter and longer journeys also introduce distinct challenges, with shorter trips amplifying the need to remain aware of one's surroundings [10]. While most commercial headsets include safety features for increased awareness, such as Meta's Quest 'Guardian', 'Space Sense,' and 'Passthrough', they primarily cater to static indoor experiences, making them unsuitable for dynamic transit environments. Quest’s 'Guardian' and 'Space Sense' introduce visible boundaries within the virtual reality, whilst 'Passthrough' temporarily provides a real-time feed of the user’s actual environment. However, these features do not help users stay aware of key external information in transit settings, such as movements of belongings, passengers, staff, or important travel announcements.

The academic community has also explored strategies for conveying real-world information during immersive experiences. Solutions predominantly focus on enhancing passerby awareness [69, 92, 94, 123], augmenting the immersive experience with physical world overlays [78, 123], including distractions [112], notifications [130], warnings [21], or 'windows'/'portals' to reality [37, 119, 121]. Some studied audio and haptic feedback [38] and redirection techniques [106, 109, 115]. These solutions consider factors like proximity [84], risk for collision [50], or user preference [31]. However, this prior work lacks specific adaptation for transit contexts. In recent work, we introduced the concept of 'Reality Anchors' for transit, seamlessly integrating cues from reality, including passengers and personal belongings, into the virtual environment [10]. This approach could potentially mitigate the barriers to the acceptance of immersive technology in transit settings. In our earlier work, simulated avatars were used to represent other co-located passengers. Therefore, it remains unclear how the utilization of Reality Anchors would influence interactions among real passengers in asymmetric immersive experiences.

2.3.2 Privacy Concerns

Immersive devices are already capable of collecting large amounts of user and environmental data [1, 32, 46, 47, 101, 120], which is necessary to support immersive experiences and environment awareness. However, this 'always-on' sensing also raises privacy implications for device users and bystanders. The novelty of immersive devices results in low awareness of what data is collected, how and why, generating concern [1, 23, 93] and barriers to wider adoption in public spaces, particularly when data collection lacks clear justification [1]. Prior research underlines that immersive device users' privacy is at risk due to the large amounts of sensor data being collected over prolonged periods, which can expose user behaviors, actions, or surrounding environments [32, 47], creating a detailed portrait of the user susceptible to malicious use.

However, while most headset users are notified of their data being collected when the device is in use, unaware bystanders can be more at risk [93]. Immersive tracking is often achieved discreetly [20], with the lack of notification, consent and potential data misuse [1, 46, 93, 101] among key bystander concerns. While previous work provides insights into the concerns that immersive device users and bystanders might have, it is paramount to understand how data sensing would be perceived in public asymmetric scenarios with varying devices, especially in transit settings where passengers are typically observed by one another and in close proximity, whilst the environment is also typically monitored for safety purposes.

2.3.3 Social Acceptability

Social acceptability refers to a device's capacity to align with dominant social norms and expectations within a specific context while avoiding social concerns, including safety, privacy, etiquette, appropriateness, causing offense, and worsening user's image [61, 66]. This is particularly crucial for unconventional and novel interfaces without wide adoption. Previous research has examined the social acceptability of wearable technologies in public spaces [60–63], including HMDs [8, 9, 26, 34, 42, 43, 65, 79, 80, 104, 118, 121], and highlighted the challenges of lacking social acceptability, particularly in crowded public spaces [118], such as transit settings [8, 9, 34, 79, 80, 104, 121]. While acceptability might improve with the growing prevalence of immersive devices driven by their usefulness, functionality, and usability [65], it remains a persistent challenge in the medium-term. Moreover, a device's social acceptability can be affected by social collisions that may occur when co-located passengers are immersed in either the real or virtual worlds [86]. Rules governing the real environment may not seamlessly transfer to the immersed user's virtual environment, potentially resulting in situations perceived as socially unacceptable, like prolonged 'staring' [35, 86]. This could become even more pronounced in asymmetric passenger experiences where multiple device use could result in unexpected social collisions, leading to social fears that are felt more acutely by some passengers than others.

2.3.4 Interaction Safety

Gestures are often required for input when engaging with immersive devices. However, in public spaces, the use of gestures extends beyond the user's interaction with the device; it becomes a shared experience for both users and observers [36]. Previous research has demonstrated that in public settings, subtle and less intrusive gestures are generally considered more acceptable [3, 5, 54, 70, 85, 99]. This is especially critical in transit settings, where the use of immersive devices in confined spaces can introduce safety risks, such as accidentally touching another passenger [77], invading personal space, or accidental collisions with nearby objects and surfaces [8, 125]. Acceptance of gestures in public spaces is further influenced by the alignment (or lack thereof) between input modalities and the perspectives of observers [5]. Acceptance improves when observers understand a gesture's purpose, although this can also depend on the user relationship and the activity [117]. Efforts to address gesture-related challenges in public spaces have explored various approaches, such as hand-to-face gestures [70], adapting input techniques for confined spaces, or optimizing space and furniture within public transport environments for immersive device interactions [58, 103, 116, 125]. Safety concerns also extend to the context of asymmetric experiences, where varying gestures are needed for different immersive applications, and users exhibit differing levels of reality awareness. These divergent interaction styles and varying awareness levels can result in confusion, unintended physical contact, and disruptions. Thus, the need to support asymmetric user experiences while prioritizing safety becomes particularly evident.

2.4 Enactments for Asymmetric Passenger Experiences

In the domain of Human-Computer Interaction (HCI) research, and beyond (e.g., engineering [67] or industry applications [136]), speculative research methods have emerged as valuable tools for envisioning potential futures and exploring alternative scenarios, including transit scenarios [4, 81]. Speculative methods typically involve a strong narrative that helps develop the speculation by positioning the participant as a character within it [83]. For instance, these narratives can actively involve participants in the imagination of a possible future, requiring them to make decisions and interact within the speculative context [83, 105]. Speculative methods encompass a diverse array of techniques, including design speculations [7, 15, 24, 25, 30, 33], fiction [12, 73, 98, 100], provocations [13], ethnographic fiction [18, 52], experiential futures [59], simulations [114], and enactments [27, 53, 89, 105]. The latter is a powerful tool in contexts where traditional research approaches fall short [102], such as when attempting to capture the complexity of future passenger scenarios that are not yet an everyday occurrence or where emerging technologies are on the cusp of development but not yet accessible.

Enactments offer a unique perspective by enabling individuals to engage in real social interactions within these speculative contexts. They allow individuals to embody or 'enact' and experience the elements of proposed varied future visions [27, 105], comparable to the principles of experience prototyping used in design, which offer contextual insights [17]. Enactments have been used to recreate a range of interactions, from personal to openly social scenarios [27]. While underexplored in transit scenarios, enactments provide a means for understanding the needs and dynamics of future passengers engaged in asymmetric experiences. By enabling the recreation of diverse participant interactions, they offer valuable insights for shaping technologies aimed at supporting in-transit experiences.

As demonstrated by the literature review, asymmetric experiences between co-located individuals can lead to intricate dynamics, influencing user behaviors, personal space, social signals, and even power imbalances or social exclusion. This issue becomes particularly pronounced when employing devices at opposite ends of the reality/virtuality spectrum. Wearing immersive devices in public settings presents further challenges, including a lack of awareness of one's surroundings, privacy concerns, social acceptability, and safety issues, all likely to remain significant in the medium-term. To gain a deeper understanding of how immersive technologies can be designed to support transit scenarios, we must explore the dynamics that asymmetric experiences create in transit contexts. To explore this, we employed speculative enactments, where participants can actively embody the vision of a future transit scenario while engaging in real interactions.

3 EXPLORING ASYMMETRIC SOCIAL EXPERIENCES IN TRANSIT

Immersive technologies offer the potential to reclaim the time spent traveling, with continually advancing headset technology suggesting that we may soon integrate immersive devices into our everyday lives, including transit scenarios. While some individuals are already utilizing these technologies during air travel [134, 135, 138], most immersive devices are not inherently designed for transit contexts. Consequently, there is a need for additional support and the incorporation of features to enhance their acceptability in dynamic public spaces, such as transit. Travelers are likely to use a range of different devices in different settings, from more to less immersive. Passengers may then engage in *asymmetric experiences* while simultaneously using various devices, each providing different levels of immersion, access to information, and interaction capabilities.

We designed a study to explore unexpected interactions, such as navigating around others or engaging in verbal exchanges, among passengers immersed in asymmetric experiences during transit. To simulate a transit scenario, we conducted lab-based enactments involving three co-located passengers using disparate devices: a mobile phone user, a VR user with occluded vision, and a VR user with occluded vision but augmented with cues from reality. For the purpose of the study, the 'Passthrough' feature was not available in either headset. Our approach enabled participants to experience a variety of unexpected interactions within the scenario, influenced by the specific device they used. We captured participants' reflections on these social interactions through a focus group.

While immersive technologies typically refer to devices like VR or AR that significantly alter or augment one's perception of reality through visual means, this study adopts a broader interpretation. We explore mobile phones as part of the reality/virtuality continuum [87], considering their capability to engage users deeply in digital content without significantly altering or occluding their perception of the surrounding environment. On a real train, there might be passengers not using any device; this aspect is not the focus of our paper. Instead, a mobile phone user reflects one end of the spectrum in our study, where the user's awareness of reality is minimally obstructed, allowing them to remain engaged in their environment. In contrast, the VR user is at the other end of the spectrum, fully immersed in content with the surrounding environment fully occluded. Using an AR device (e.g. HoloLens) in the enactment was intentionally avoided, as AR devices do not occlude reality to the same extent that VR devices do. In our work, we specifically wanted to explore these higher levels of occlusion that lead to asymmetric experiences between passengers. Therefore, the VR user with cues from reality represents an intermediary point, blending elements of virtuality and reality. This intermediary point is an iteration of the 'Reality Anchors' concept introduced in our earlier work [10] using reference points from reality, positioned in virtuality, to help maintain awareness of the environment, improving perceived safety, social acceptability, and comfort while sustaining immersion. This paper evaluates the anchors in a novel manner, not explored in earlier work.

In our enactment method, participants were tasked to imagine that they were traveling on a train and watching a documentary to pass the time. To create realistic unexpected interactions between them, we provided timed individual prompts that would direct participants to perform actions, e.g. moving seats, or asking a question of another traveler. Using this enactment method, we ask the following research questions:

RQ1: How do unexpected passenger interactions influence the acceptance of immersive technologies in transit contexts?

RQ2: How do passengers experience unexpected interactions during asymmetric experiences with disparate immersive devices?

RQ3: Can cues from reality improve how immersed users manage unexpected passenger interactions in transit contexts?

3.1 Enactment Method

In our study, we employed enactments as a method to create a travel scenario featuring three co-located passenger personas immersed in asymmetric experiences. This method involves participants in realistic social interactions within speculative contexts, allowing them to embody and enact elements of potential future scenarios. Enactments serve as a valuable research tool for observing authentic human responses to new technologies in a controlled setting, thereby providing insights into societal impacts and behaviors in potential future environments [27]. The procedure of enactments includes designing these speculative scenarios, assigning roles or tasks to participants, and then observing their behaviors and interactions.

Enactment methods follow a strong narrative structure, which requires a different kind of experimental design when compared to traditional lab studies that depend on variables or conditions. This narrative approach involves creating a story or sequence of events that participants follow, which helps them immerse themselves in the scenario and engage with the context more deeply. This narrative approach, commonly used in speculative methods [12, 67, 68, 73, 74, 83, 111], enables researchers to investigate and convey potential futures for technology [111]. By employing narratives, we can explore new technological possibilities and examine the potential user interactions and societal impact these technologies will have.

3.2 Procedure

Before the study started, each participant was given an information sheet and a consent form to read through and sign. They were then assigned a persona (as described in section 3.3) at random. The VR user and the VR user with Reality Anchors were given a tutorial lasting roughly five minutes that showed how to use the application on the headset and the controllers.

To prepare participants for the enactment experience, the study started with an ice-breaker from improvisational theatre [143]. All three participants were asked to imagine that they were standing next to a park bench, which was represented by the row of seats used in the study. In the ice-breaker, one participant needs to sit on the "bench" and pretend to be engaged in an activity, such as reading the newspaper, watching the birds, etc., but they must always remain seated. Another participant joins the ice-breaker and pretends to be a pedestrian. Their job is to copy the activity of the "bench" occupant and get them to laugh or leave the seat in under one minute. No physical contact is allowed. If the "bench" occupant laughs or leaves their seat the "pedestrian" takes their place. The game was repeated until all participants played the "bench occupant" and the "pedestrian" roles, taking around five minutes. The ice-breaker played a crucial role in helping participants become comfortable with assuming roles, ensuring they could fully engage in the enactment experience.

Following the ice-breaker, the study would begin. The immersive headset user started the study on the seats to calibrate the depth cameras used in this study (refer to 3.4.2) based on their position, followed by the mobile and VR users entering the scene and taking their places on the seats (Figure 1). All participants started their applications simultaneously to formally begin the enactment. This started the documentary playback and the beginning of their traveling experience. The enactment ran for ten minutes, during which the application instructed the participants to initiate unexpected interactions. Ten minutes within VR allows for a rich experience, in line with previous research in HCI employing HMDs [26, 78, 84], while minimizing fatigue and cybersickness. After the enactment, the mobile and VR headset users were given a preview of the Reality Anchors experience as part of the debrief. At this point, all participants were debriefed on each other's personas and devices used.

After participants were debriefed, a focus group interview was conducted to discuss their experiences. First, the interview explored participants' perceptions of the interactions they experienced and initiated during the enactment. The interview then addressed the social acceptability of their actions and those of other passengers. Furthermore, the interview reviewed the use of immersive technology in various transit settings and gathered reflections on Reality Anchors. For the complete interview guide, please see Appendix A. During the interview, participants were probed with follow-up questions (e.g., "why do you think that", and "can you tell me more about X") when necessary (e.g., to further investigate the comments made, clarify ideas, or if one or several participants were especially quiet). Interviews took approximately 30 minutes and were audio recorded, anonymized, and later transcribed for analysis.

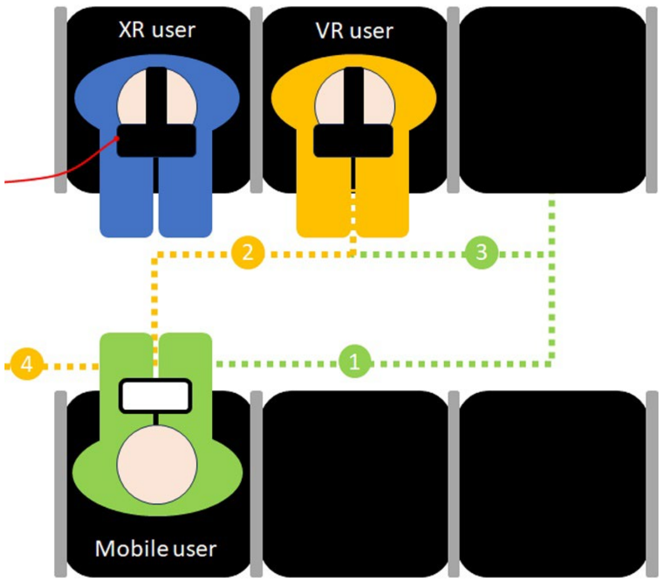

Figure 1: start seating positions and movements of the three co-located personas (XR user refers to the VR user with Reality Anchors enabled).

3.2.1 Passenger Interaction Prompts During Enactment

Participants used one of three devices: a commercially available VR headset, a commercially available VR headset with Reality Anchors enabled, or a mobile device, to represent a range of user experiences. The decision to offer three different experiences enabled participants to develop unique perspectives to share in focus group discussions.

To emulate an authentic in-transit environment and create real unexpected interaction scenarios, individual persona actions were intentionally not disclosed in advance; instead, they were delivered as prompts (for the full list of prompts see Appendix B) on participants' devices in real-time (Figure 4). Each persona was designed to represent divergent ways that people deal with a travel experience. For example, someone may be more active or involved when traveling, changing seats, and engaging in conversations with fellow passengers. In contrast, another passenger may prefer a more passive experience, choosing to disengage from the transit environment. While the selected interactions were scripted, they incorporated an element of unpredictability for all personas. For instance, even a VR persona, typically associated with disengagement, was provided with a question to ask another passenger.

The scripted actions were active interactions that involved other passengers, as well as passive interactions, performed in a self-contained manner, and included:

- sitting in front of another passenger (entering/leaving another passenger's field of view), *active*;
- sitting next to another passenger (entering/leaving another passenger's intimate zone), *active*;
- initiating a quick question, *active*;
- initiating a question that requires more involved conversation, *active*;
- changing seats, *passive*;
- moving vigorously, *passive*;
- dropping items, *passive*.

Actions involving other passengers were inspired by related literature to explore realistic challenges that may arise in unexpected interactions among passengers using disparate devices. For instance, entering another person's field of view could lead to complex interactions between users with headsets and those without, occasionally resulting in perceptions of staring [86], generating unique interaction dynamics. Drawing from proxemics theory [48], the decision to seat passengers next to one another replicated the discomfort that can arise when individuals are in close proximity within their intimate zone. However, when a user is immersed in virtual content, traditional physical space norms may not apply, potentially leading to clashes in social affordances when passengers in different states of asymmetric experiences (e.g., using an immersive device or a mobile phone) sit together. Previous research on passenger behaviors on public transport has shown that passengers often engage in non-visual activities, such as listening to music, to disengage from conversations with fellow passengers while maintaining a friendly atmosphere [113]. Nevertheless, it remains unclear how verbal interactions would be perceived when all passengers are engaged in asymmetric experiences, with some encountering visual occlusion, influencing our choice to include verbal interactions. Conversely, passive actions consisted of a set of behaviors that were not reliant on direct engagement with other passengers and were instead observed by them.

3.3 Personas

In each session, three participants adopted traveler personas, each using individual devices to watch a documentary while in transit. Personas were individually and randomly assigned, with participants aware only of their own. Recognizing our study's speculative nature, we explored a set range of behaviors and device interactions instead of cataloging every personality and device combination. Participants were given specific instructions related to their device usage and task, but not on how to embody the personality traits of their personas, to encourage genuine reactions to prompts.

3.3.1 'Mobile Phone User' Persona

The mobile user persona is inspired by a traveler who wants a more active experience during their journey. Their device does not limit their movements or awareness, allowing them to move around freely and engage with other passengers. Prior to the start of the experience, they received the following instruction: "You are traveling on a train that goes to Edinburgh. To pass the time, you are using your phone to watch a documentary" at the start of the study. The persona’s scripted actions, delivered as real-time prompts (see Appendix B) on their device, included: sitting in front of the VR headset with Reality Anchors user, standing up and doing some stretches, changing seats, sitting next to the VR headset with Reality Anchors user, dropping a set of pens.

3.3.2 'VR Headset User' Persona

The VR user persona is inspired by a traveler who may prefer to disengage from the transit environment but may still desire to interact with other passengers during their journey. This persona represents an intriguing tension between engagement and disengagement, as it reflects the idea that in various contexts, people may choose to engage or disengage with other passengers [113]. The VR user persona was given the following instruction: "You are traveling to Edinburgh by train to see a show at the theatre. To occupy your time, you are taking a VR headset with you and plan to watch a documentary" at the start of the study. The persona’s scripted actions, delivered as real-time prompts (see Appendix B) on their device, included: sitting next to the VR headset with Reality Anchors user, asking a quick question, changing seats, sitting in front of the VR headset with Reality Anchors user.

3.3.3 'VR Headset with Reality Anchors User' Persona

This user persona is inspired by a traveler who is an early adopter of immersive technologies. They prefer to stay settled in their seat until they reach their destination, utilizing technology to facilitate awareness and interaction as they desire. However, they are likely to engage with other passengers. They were given the following instruction: "You are traveling on a train to Edinburgh. To pass the time you are using an immersive technology headset to watch a documentary" at the start of the study. The persona's scripted actions, delivered as real-time prompts (see Appendix B) on their device, included: initiating a quick question and initiating a question that requires more involved conversation.

3.4 Enactment Setup

In the following sections, we describe the physical lab environment where the enactments were staged, the hardware used by participants, the software for the nature documentary application that delivered timed prompts, and the visualization choices for Reality Anchors.

3.4.1 Physical Lab Environment

The study was conducted in a lab environment, where we recreated a typical transit seating arrangement. Recognizing that public transport systems offer a variety of seating configurations, from individual to communal arrangements [85], we selected a face-to-face setup for its potential to foster passenger interactions. This setup involved arranging two rows of AirAsia airplane seats (as depicted in Figure 2), a configuration commonly found in trains or subways, where passengers are facing each other and sitting next to each other, often intruding into other passengers' personal space. The seats were positioned 77 centimeters apart, facing one another. Each seat had dimensions of 64 centimeters in length, 148 centimeters in width, and 120 centimeters in height.

Figure 2: three co-located users enacting a transit scenario; b) seats used in the scenario; c) A Kinect camera for body tracking.

3.4.2 Hardware

For the persona devices, we utilized a Google Pixel 7 mobile phone and two Meta Quest 2 VR headsets. For the VR headset with Reality Anchors device, we used an Azure Kinect camera in conjunction with the Quest 2 for real-time tracking of other participants. These participants were represented as Reality Anchors, displayed in the form of stick skeletons depicting their upper bodies. For the Anchor that represented the seating furniture, we used 3D scans of the seats (Figure 3). While the immersive tracking setup was deliberately visible, it was not explicitly disclosed. Participants were intentionally kept unaware of each other's setups and available information, creating real interactions among them. As audio was not under investigation in the study, open-ear audio was utilized and held constant, with playback through the device speakers. For VR headset users, the audio played through the headset speakers, while for mobile users, it was delivered through the phone speakers.

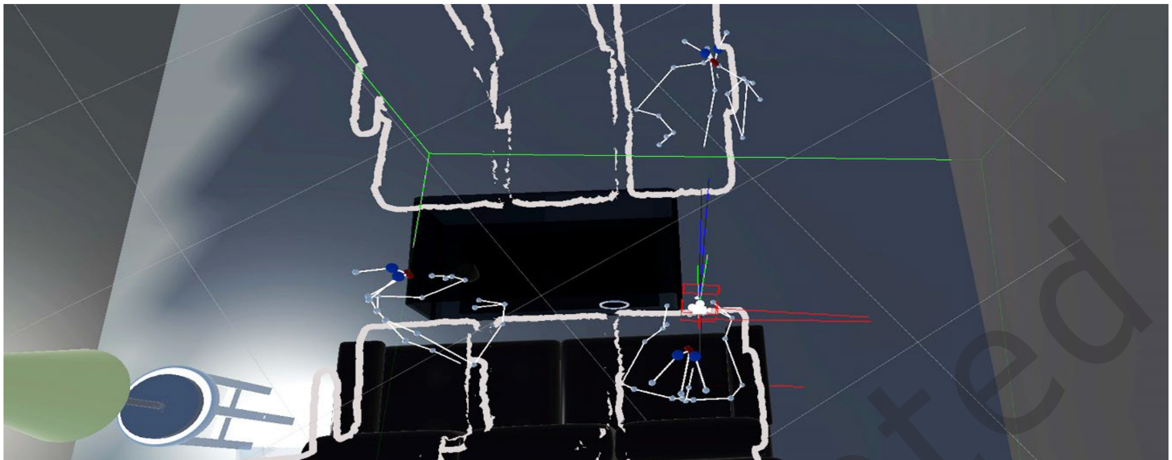

Figure 3: 'train seats' and three co-located 'passengers' as Reality Anchors.

3.4.3 Software

All three personas watched the same nature documentary content on their respective devices to prevent the introduction of confounding variables. To simulate unexpected interactions, participants' applications were designed with a timed prompt that would appear as a pop-up on their device (Figure 4), directing them to perform a specific action. The documentary was paused automatically when the pop-up appeared to ensure participants could focus on the prompt. All device content was created and delivered using Unity. For the users wearing VR headsets, the documentary was shown within a virtual cinema setup (Figure 5), while mobile users viewed the same content through a custom-made video player application. One VR headset was augmented with passenger and seat anchors to support in-transit interactions.

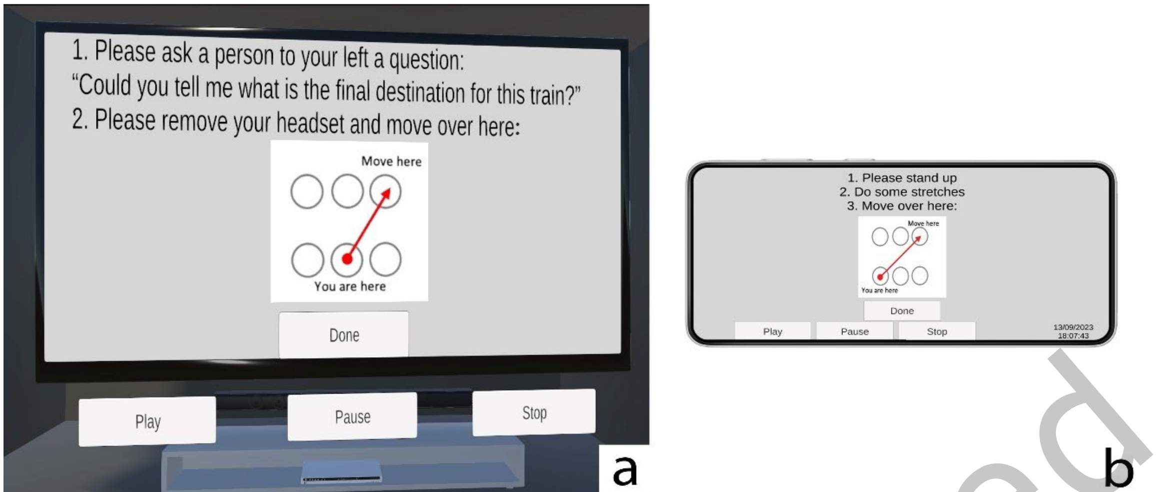

Figure 4: a) sample instruction prompt on 'VR' and 'VR with Reality Anchors' personas' devices; b) sample instruction prompt on 'Mobile Phone' persona's device.

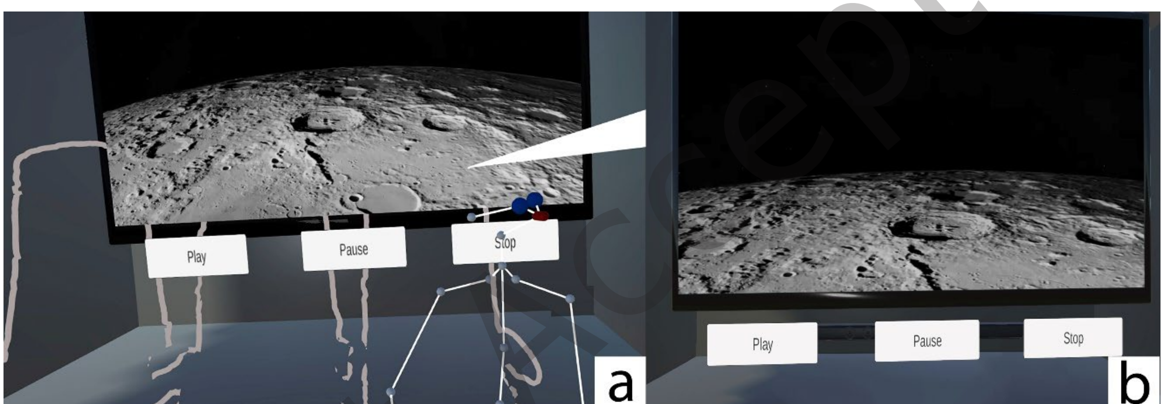

Figure 5: virtual cinema experience as seen by a) VR user with 'Reality Anchors' enabled, b) VR user's perspective.

3.4.4 Reality Anchors

In our prior work [9, 10], we introduced the concept of Reality Anchors to enhance the use of immersive headsets in transit settings. Reality Anchors aim to 'anchor' or ground virtual reality within the real world by providing cues from reality as reference points in virtual environments. Anchoring in reality helps sustain imagination and maintain a clear contrast between virtual and real worlds, which is crucial for a contiguous user experience across realities [51]. Our earlier explorations of the concept [9, 10] have emphasized the necessity of passenger anchors (Reality Anchors visualizing other passengers) for immersive headsets in transit. It has also been noted that, while furniture anchors (visualizing seats, walls, handles, etc.) can be distracting, their inclusion is essential to ground the passenger in the scene, as their absence can distort references to real objects, considered unacceptable in a transit scenario [10]. To minimize the distraction caused by furniture anchors, we adjusted their depth to ensure that they did not obstruct the cinema screen.

To visualize Reality Anchors, we opted for a minimal viable visual representation, which consists of outlines and skeletons of the other two passengers (see Figure 3 and Figure 6). We did this to maximize immersion in the documentary and to avoid introducing confounding factors associated with realistic avatars, particularly concerning anonymity [88] and distraction [10]. Future research could, however, explore the use of high-fidelity avatars as Reality Anchors.

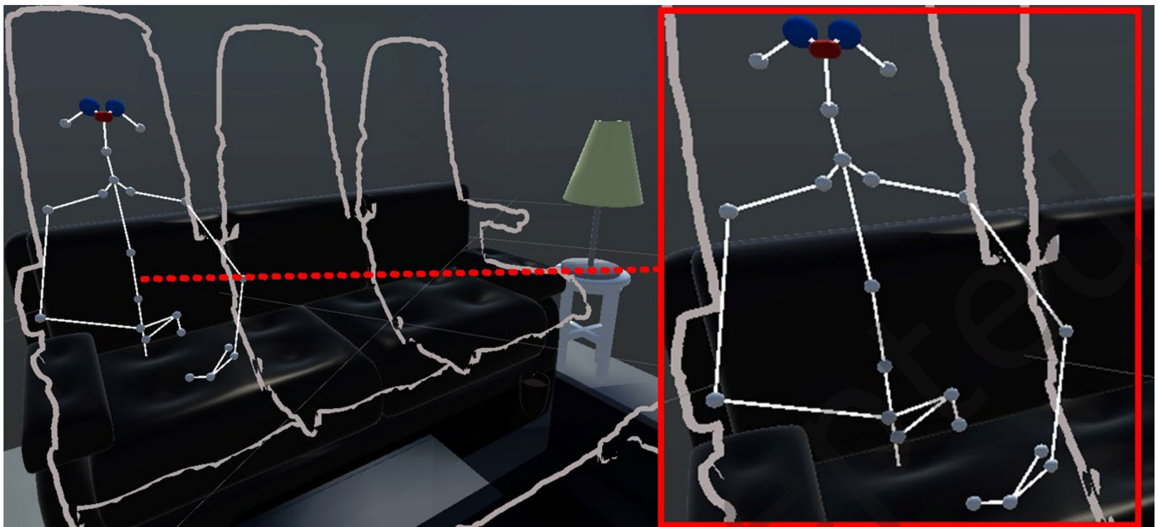

Figure 6: an example of an upper body skeleton used to represent other passengers' anchors.

We selected to only display the upper body of the skeletons, rather than the full body. Previous studies have demonstrated the effectiveness of this approach in social situations when the primary focus is on the upper body or when the available space is limited [129]. This choice suited our scenario where passengers often remained seated, and minimizing distractions from the video screen was essential. Skeleton joints and head angle were updated in real-time, allowing us to accurately portray the movement of other passengers' bodies but only to the immersive headset with Reality Anchor persona. Minimal visualizations were deliberately visually different from everything else in the scene, ensuring a clear distinction between virtual objects and Reality Anchors.

3.5 Participants

In total 21 participants (8 females, 13 males, mean age = 32 years, SD = 9), split into 7 groups of 3, took part. These groups included both strangers and participants who were friends or knew each other. The majority were students, 16 had used a VR headset at least once, and 5 had never used one before. The mix of experience levels reflects a diverse range of device familiarity that users might encounter in a transit setting. The study took approximately 60 minutes and participants were compensated for their time with £10 Amazon vouchers. The study was approved by the university ethics committee. Full details of participant demographics are provided in Appendix C.

4 RESULTS

Once transcribed, participant statements from interview transcripts were manually coded using open coding [22], adhering to an inductive approach. Open codes were used to annotate the interview transcripts with short phrases identifying concepts in the data. An example would be a quote: *"If he really talked to me or talked to someone on his VR device?"* (G2, P6, M), coded as 'intended respondent'. Each statement was assigned an emergent code, which was iterated over several cycles and used to re-code the transcripts until no new codes were needed. Subsequently, a thematic analysis [16] approach was adopted by examining the initial codes and searching for candidate themes and sub-themes. Multiple coding was allowed, where a code could be shared across sub-themes. For example, the theme 'Navigating interactions' had a sub-theme of 'Responding' and a sub-theme of 'Initiating', both of which shared an open code of 'Eye-gaze'. Themes that could not be fully supported by participants' quotes were excluded. A single researcher performed the coding with discussion and iteration of the codes with another researcher. For visualizing the data and creating a thematic map, a Miro board was used. For the purpose of detailing the results, each participant was assigned a code composed of a group number (1-7), participant number (1-21), and the device used (M: mobile phone, VR: virtual reality headset, XR: virtual reality with Reality Anchors enabled headset).

4.1 Passive Versus Active Participation in Passenger Interactions

During the interview, participants discussed different actions they were asked to perform and other interactions they would imagine engaging in whilst traveling. Interactions that do not require the active initiation by, or involvement of, headset wearers were seen as mostly acceptable. This included verbal interactions between other passengers, "*when you hear some kind of mumbling or like people are whispering around you, so you get the notion this person doesn't seem like they're actually interacting with me*" (G1, P1, VR), 'quick queries': "*if somebody asks me the time, I would be fine with them not taking their headset off […]it's too much work just to take off the headset, just to ask for the time*" (G4, P12, M) or verbal interactions initiated by other passengers: "*if I am using the headset and somebody asks me a question, it doesn't really bother me to give the answer*" (G4, P10, VR). Passive non-verbal interactions were also seen as acceptable, including moving around and sitting next to/ in front of headset wearers, and were perceived as 'normal' and 'to be expected' in public transport.

However, interactions that were worrisome or required active participation were perceived as less acceptable when VR or immersive headset users were involved. Most problematic activities were back-and-forth conversations, with one participant noting: "*maybe it was okay to ask for the time it's a quick question, quick answer […] but to start a conversation? […] it felt strange"* (G6, P17, XR). For non-verbal interactions, concerns arise when interactions might require a reaction and include disturbances or risk to safety: "*like the pen dropping or whatever. It's the kind of thing that I probably would have wanted to see what was going on, to make sure everything was okay, if somebody needed help*" (G3, P8, XR). Such interactions were most uncomfortable for VR users: "*I just heard some sounds, but then I was I wasn't sure what it was. So, I was just sitting there confused. Like, what? Did something break?"* (G3, P7, VR), whilst immersive headset wearers were reassured by the ability to monitor the environment: "*because I could see people around me, I was pretty aware that things around me seem to be progressing relatively normally*" (G3, P8, XR).

Overall, participants' answers showed that verbal interactions require more involvement and create more complex dynamics between passengers engaged in asymmetric experiences. Considering the intricate nature of verbal interactions in contrast to non-verbal ones, the following section will present the challenges pertaining to this specific type of interaction.

4.1.1 Summary

Our findings suggest that the level of engagement required by the unexpected interaction (passive, active or reactive) and the nature of the interaction (verbal or non-verbal) affect how acceptable these interactions are when immersive technologies are used, influencing their overall acceptance in transit contexts (RQ1). Non-verbal interactions that only demanded passive presence from the headset wearers were perceived as the most comfortable during transit. This insight highlights the importance of designing immersive technologies that account for varying degrees of passenger engagement and types of interaction to enhance user comfort and social acceptability in transit environments. While previous research has emphasized the importance of engagement levels in collaborative settings [44], our study extends these insights to asymmetric transit scenarios, emphasizing the impact of engagement level and interaction type on the acceptance of immersive technology.

4.2 Assessing, Initiating, and Responding to Verbal Interactions in Transit

4.2.1 Assessing Receptivity and Initiating an Interaction

Prior to initiating a verbal interaction, participants expressed the need to assess if their fellow passengers would be receptive. One participant noted that knowing that "*this is the right person to ask*" and "*look friendly*" (G1, P2, XR) are key indicators. Most participants felt that fundamental social norms for assessing the other passenger and initiating contact were challenging when the action was initiated by the immersive and VR headset users. Participants relied on non-verbal cues, such as facial expressions: "*we do not really know the facial expressions…I cannot really capture the whole thing that reflects the person next to me*" (G4, P10, VR) to make the decision. Eye contact was a key missing cue that most participants felt they would resolve by removing their headset: *"I think I wouldn't ask a question with the headset on I would move it up, have an eye contact first and then have the interaction*" (G5, P13, VR). Participants felt that not doing this would come across as rude: "*In a real-life situation, I'd find that a bit rude. Like if someone talks to you and like, isn't looking at you*" (G3, P9, M), or selfish: "*seems like I was ignoring the person around me and then when I need something I just approach the person*" (G4, P10, VR).

They emphasized the importance of alternative protocols to grab attention, especially if direct eye contact is not possible. For instance, gestures such as waving were suggested: "*let's say I'm watching and the skeleton was doing like that, like waving, I would stop and remove the headset and then interact"* (G5, P13, VR), or verbally announcing the intention to talk: "*when […] they just ask me it's impolite. You can say, sorry, excuse me*" (G1, P3, M). However, as in Section 4.1, removing the headset was not seen by some as a necessity replying to another passenger: "*if I'm wearing the headset, someone asks me a question, I'm not going to take off the headset. I'm focusing*" (G1, P1, VR). The rules for verbal interactions would also be less strictly followed when the other party was familiar, such as "*friends*" (G4, P11, XR) or "*family*" (G1, P3, M).

4.2.2 Responding to Verbal Interactions in Transit

Participants found that responding to interactions involving headset wearers was confusing. It was unclear if the interaction was taking place in the virtual or the real environment: "*did he really talk to me or talked to someone on his VR device?"* (G2, P6, M), or who was the intended respondent to the verbal interaction: "*he's in VR world and I wasn't sure if he was addressing me or not"* (G5, P15, M), especially when there were multiple people in close proximity: "*if there were three people or two people around them, I wouldn't know who [sic] they were asking it to*" (G3, P8, XR). Confusion was also experienced by the headset wearers trying to determine if they were the intended recipient of interaction from other passengers: "*maybe I would just take* *it off to make sure that they're asking me [...] how would I know that actually they're asking me or they're asking someone else*? (G1, P2, XR). No participants indicated their intentions verbally or through touch, yet a few attempted to communicate with body language. One participant shared, '*when I asked a question, I tried to signal that I was asking him by leaning in... And he just completely blanked me...*' (G3, P8, XR). As noticing eye contact or reading body language was not possible, some expected non-visual cues to indicate they are the intended respondents for the interaction: "*If it was for me, then someone would tap me or, I don't know, like, nudge my leg*" (G7, P19, VR), but this was not acceptable for all: "*if you want to catch the attention of a person or a passenger with your headset, poking them, I don't think it's a good option*" (G5, P13, VR).

4.2.3 Summary

We found that unexpected verbal interactions involving immersive headset users disrupt established social norms and communication practices for initiation and responding, thus negatively impacting the acceptance of immersive technology in transit settings (RQ1). Specifically, the absence of non-verbal social cues, such as facial expressions, gestures, and eye contact, are essential but often missing in interactions involving headset users. This aligns with previous research, which has also underscored the significance of facial cues and eye contact in enabling meaningful communication between HMD users and non-users [19, 76]. However, our findings suggest that social norms may be more flexible in interactions among individuals with prior acquaintance. Ultimately, our work underscores the importance of enhancing support for key social cues in asymmetric contexts to better facilitate passenger interactions.

4.3 Disembodiment and Disconnection from the Transit Environment

During the focus groups, those who used VR headsets consistently reported a distinct sense of disembodiment and disconnection from the real environment: "*I was just fully immersed in it [...] it felt like I was in a totally different world*" (G3, P7, VR). Participants mentioned a noticeable lack of presence from other passengers, leading some to forget where they were and making it challenging to shift focus from virtual content to engaging fellow passengers: "*I had to go out of my virtual reality into this real world, see where everything was, and then ask, and then do what I need to do, and then get back*" (G7, P19, VR). This became more difficult during asymmetric experiences: "*If one of us is not using the technology, but both of them are using the technology, maybe it's not really acceptable*" (G6, P17, XR), more so for interactions between a user in the virtual environment another in the real world: "*to do an icebreaker or spark a conversation in VR with a non-VR user, that feels like it's a hard barrier*" (G7, P21, M). Interestingly, for some VR users, disengagement from the real environment helped them feel less awkward about the situation: "*if you're wearing the headset, you can't really see people's expressions or faces. Can't really see what they're thinking of you anyway. So, I guess it matters less*" (G2, P4, VR). In contrast, some participants using immersive headsets reported maintaining a connection to the external environment, allowing them greater awareness of their surroundings: "*when I immerse in my own world, I could see what happened in my surroundings. So [...] it feels like [I Am] still connected with the world*" (G4, P11, XR), with one participant noting a sense of social presence: "*I definitely felt inside a virtual social space*" (G3, P8, XR). Fellow passengers felt a sense of disconnect: "*it's like a bit strange seeing people with the headsets on because they're here in front of me, but they're somewhere else completely*" (G4, P12, M), with some feeling that headset wearers are 'untouchable': "*it is [...] making them untouchable because if I want to talk to them, say something, or make the conversation, it's quite impossible because they are with their device*" (G2, P6, M).

4.3.1 Summary

Users immersed in virtual reality by wearing a headset experience disconnection from fellow passengers and the transit environment, making it challenging to engage in unexpected interactions. This sentiment was echoed by other passengers who found headset-wearers unapproachable and challenging to engage with (RQ2). Interactions between passengers were especially difficult when the asymmetric experiences were at opposite ends of the reality spectrum, such as a VR user and a smartphone user. While previous work highlighted disconnection between HMD and non-HMD users [19, 45], our findings suggest that asymmetric experiences not only create barriers but also contribute to a sense of unapproachability among passengers, underscoring the need for immersive technology designs that foster social connectivity.

4.4 Breach of Trust by Immersive Tracking and Altered Behaviors

The sense of disconnect also influenced the behavior of other passengers in the transit scenario. At the start of the study, participants remained unaware that one of the headset wearers had an enhanced view of reality. This led to behaviors that emphasized this sense of detachment: "*I thought at first that they can't see me, so maybe I can just do something and they are not going to notice. Like, maybe I would do something weird in their face, and then they will not…[know]"* (G2, P6, M). Another participant also shared a similar experience: "*with the stretching, I was like fine because I just assumed they did not know I was in front of them, so I thought it was fine to do*" (G4, P12, M). Others sought a sense of anonymity, with one individual sharing: *"I thought I was a bit incognito"* (G4, P12, M). This exhibited this desire for discretion by keeping a distance: "*I did feel weird about going to sit next to someone where I knew they can't see me and probably would be surprised by my presence*" (G3, P9, M) with participants keen to avoid engaging unless necessary: "*it would have to be an absolute emergency to actually interrupt someone from this to ask a question"* (G6, P17, XR). However, passenger behaviors were perceived differently upon learning about immersive tracking. Most felt uncomfortable not having known they were being tracked: "*when I realized he could see me the entire time, it felt almost like a betrayal. If I see someone wearing a sleeping mask, I don't assume that they know what I'm doing*" (G3, P9, M). This also altered the perceived actions passengers could take near headset wearers, limiting their movements: "*I wouldn't move around because I don't want to disturb people"*, or avoiding sitting directly in front of other passengers: "*I would probably move so they're not right in front of the screen"* (G7, P19, VR). Immersive headset users also reacted negatively to discovering that other users were not aware they were being observed: "*now that I know that everyone else didn't have the same view, I felt like I was quite rude"* (G3, P8, XR). Most participants expressed concerns about their privacy and being recorded: "*maybe the headset can record what he is seeing around him...So what if he's recording what's around him? So that includes me. So that's a cause of concern"* (G1, P1, VR), with a desire to be warned about real-time tracking: "*there wasn't anything, no context, cue or clue to show me that MR user is seeing the things around him. I think it might be a good thing with such devices if they have an indicator saying he can see, he's seeing things around him*" (G1, P1, VR).

4.4.1 Summary

Asymmetric user experiences can influence passengers' behaviors during unexpected interactions. These behaviors include physical movements around headset users, reluctance to engage with them, and for headset users with Reality Anchors, adjusting seating to avoid distractions (RQ2). Immersive tracking also raised privacy concerns among passengers, with the majority expressing discomfort due to the absence of notifications and warnings about tracking activities. Previous work has noted that device asymmetry can lead to power imbalances between users and bystanders [95, 127], potentially leaving HMD users vulnerable.

Our findings highlight how power imbalances can shift with varied access to information, with bystanders feeling more vulnerable upon learning that VR with Reality Anchors users could remain aware of their whereabouts. The ambiguity regarding what information each person possesses further complicates passenger interactions, leading to skewed social dynamics and altered behaviors, e.g., adjusting seating or movement patterns.

4.5 Reality Anchors for Supporting Passive Awareness and Missing Social Cues

4.5.1 Enhancing Passive Awareness

We also investigated how Reality Anchors can support unexpected interactions with immersive technology users and effectively alleviate physical safety concerns by reassuring users about passenger body movements. Further Anchor detail is still needed to support passenger interactions that require a reaction or active participation, e.g. a conversation. Immersive headset users appreciated the increased level of awareness anchors provided and felt that it allowed them to focus on the task with more ease: "*you can still focus on what you're doing. But then you are aware there's someone else besides you, or behind you or in front of you*" (G2, P6, M). Anchors allowed them to monitor their environment for safety concerns: "*but nothing was really concerning because I could infer from seeing people that nothing was wrong, particularly"* (G3, P8, XR), described as a `*presence indicator*' (G3, P8, XR) that requires little cognitive effort to monitor the environment: "*I was very aware of any pretty much as soon as anything happened around me. I was instantly aware, although I didn't have to focus on it*" (G3, P8, XR). This also made the experience feel less isolating: "*I felt mostly more normal than I would be in most VR setups, where you're completely in a different situation when you're really boxed in*" (G3, P8, XR). However, the anchors could also be distracting: "*the little skeleton guys to be, like, kind of distracting, not super distracting. I could still like, tune in and watch the video, but I was definitely drawn to it whenever there was action happening around me*" (G3, P8, XR), but some felt this was an acceptable compromise for increased awareness: "*at some points, I feel like it's distracting because the person in front of me was moving his head, his hand... but at the same time it is comfortable seeing that rather than not knowing what the people are doing*" (G1, P2, XR). The feelings were also shared by some observers, who, upon debriefing, felt that the anchors were useful for physical safety: "*I would have actually preferred that as well. Because it makes it more personal, where you are more aware of your surroundings*" (G2, P4, VR).

4.5.2 Missing Social Cues for Comprehensive Passenger Interactions

Finally, the visual representation of the other passengers received mixed opinions. Some participants felt that the minimal visual representation was appropriate: "*it made asking them ambiguous and awkward, but it also meant that I didn't really feel like I was, like, spying*" (G3, P8, XR). Others felt the lack of detail fostered ambiguity and impeded engagement with others: "*I kind of know what they are doing but also, I don't really know what we're doing and can't really judge these people*" (G3, P9, M). Linking to the earlier findings, participants wanted to know more about the receptivity of the other passengers, including if they were wearing a headset themselves: "*I can't tell if the skeleton is wearing a VR headset, or is not which is quite an important distinction"* (G3, P8, XR), as well as the state they were in: "*knowing people were there was good information, but it was kind of ambiguous as to how they were, what state they were in, and if they will, would be receptive*" (G3, P8, XR). To better gauge receptivity, an option for eye contact was desired: "*you need something else, like, some sort of way that people in the front that could tell you, like, where your visual attention is, so you can tell if you're being talked to"* (G6, P16, VR). Even though skeletons had eyes, assessing the necessary gaze direction in VR was still complicated: "*The skeleton does not give enough information on* *whether they are looking at me or not... or maybe there were some eyes?*" (G1, P2, XR), without further indication that an interaction is being initiated.

4.5.3 Summary

The use of cues from reality, referred to as Reality Anchors, can effectively help alleviate physical safety concerns associated with passenger interactions by providing users with reassurance about passenger body movements. However, further detail in the anchors, for example, facial expression or eye contact, is necessary to facilitate comprehensive passenger interactions that involve reactions or active participation, such as engaging in a back-and-forth conversation (RQ3). This highlights the limitations of current reality awareness solutions in fully supporting passenger interactions, emphasizing the need for further development to reduce barriers between passengers while preserving individuals' privacy. This work builds upon existing research that introduced the concept of Reality Anchors [10], taking the novel step of applying them with actual passengers and eliciting realistic reactions.

5 DISCUSSION

5.1 Personal Disengagement Versus Social Interactions

Our findings highlight the challenges of engaging with passengers immersed in diverse experiences with varying levels of available information and ability to interact. Scenarios in which users engage in similar experiences enable smoother interaction: "*[if the] three of us using the technology, similar technology, so it's fine, because we are in the same [social] circle, so it's fine*" (G6, P18, P), but asymmetric experiences become a substantial barrier. This is particularly pronounced with technologies from different ends of realities: "*to do an icebreaker or spark a conversation in VR with a non-VR user, that feels like it's a hard barrier*" (G7, P21, M). This echoes the existing practice of using electronic devices, such as mobiles or laptops, to create disengagement from uncomfortable social interactions with fellow passengers [113, 131] in confined spaces [97].

Immersive technologies extend the concept of disengagement even further by allowing users to immerse themselves in new, customized realities. As a result, the divide between passengers and their immediate transit environment is magnified, intensifying the sense of disconnection. Not everyone seeks such disconnection; some individuals prioritize maintaining awareness of their environment [8] and currently might opt for less immersive technologies such as mobiles or AR devices feeling reluctant to use an immersive headset despite its capabilities (G3, P7, VR; G6, P17, XR). Therefore, as immersive technologies become more accessible to broader audiences, managing asymmetric experiences in public spaces will become a challenge. These asymmetric experiences create a disruptive transition period as social norms evolve to accommodate the technological shift, highlighting the need to explore how immersive technologies can support social interactions during this transition. Looking to the far future, we can imagine that immersive devices will become more homogenous in terms of capabilities and affordances, stabilizing norms and expectations around how people use such devices in co-located public settings. Just as we have adapted to passengers using headphones, phones, laptops, or tablets, this unified approach would establish familiar norms for interaction, streamlining the passenger experience. However, individual user behaviors and preferences will remain varied. While some passengers may seek to engage with others, there will be those who prefer to shield themselves [86]. Consequently, immersive devices need to support a wide spectrum of user preferences, facilitating both connection and privacy within public transit environments.

5.2 The Gaze Gap in Immersive Technologies

Non-verbal cues, encompassing body language, facial expressions, and gaze, play a pivotal role in facilitating human interactions [14, 91]. Gaze serves the purpose of evaluating interaction receptivity and indicating intended respondents, as emphasized in our work. The necessity to address the absence of gaze has long driven both academic and industry efforts. Research efforts have included simulating gaze on headsets [28], and some have incorporated additional information, such as the full face of the user [76]. Industry products are also increasingly focusing on resolving the absence of gaze, exemplified by the recent introduction of the Apple Vision Pro immersive headset [133], which can simulate a digital version of a user's eyes to other people nearby via a front-mounted screen. This simulation can adjust based on the user's level of engagement in the activity to indicate their receptiveness to outsiders [144]. However, some initial reactions describe it as 'creepy' [145] or 'uncanny' [146], raising questions about the suitability of this approach.

While the gaze issues caused by current headset form factors [14] may be resolved in future, our work shows that the requirements for gaze pose additional challenges in asymmetric experiences. Even with flawless and unobscured gaze simulation, navigating between real and virtual worlds remains challenging. Communication could occur in either space simultaneously, highlighting the issue of 'social collision' where virtual content might collide with the real surroundings [86]. For instance, a headset wearer might be engaged in a conversation with someone in their virtual view, not visible to others, or attempting to communicate with a person in the same physical space. This challenge is illustrated by one of our participants who queried: "*did he really talk to me or talked to someone on his VR device?*" (G2, P6, M). Furthermore, in transit scenarios, gaze needs to serve a bi-directional purpose, allowing both immersive and non-immersive users to convey their intention for interaction or confirm receipt. Challenges might also arise when multiple passengers want to interact but have varied levels of non-verbal cues available. Additional research is necessary to investigate if and how gaze could be used to bridge the gap between virtual and real worlds to facilitate smooth interactions amongst co-located users in asymmetric experiences.

5.3 User Experience of Immersive Tracking

In our study, we took a distinct approach by exploring three immersion levels in device setups, one of which included real-time skeleton tracking. By exposing participants to immersive tracking, we provided them with first-hand experience of asymmetric interactions and the privacy implications, in contrast to previous work reliant on more hypothetical approaches [1, 93, 101]. While our study used cameras mounted within the environment, we anticipate similar privacy dynamics and concerns to arise with cameras mounted on headsets. In earlier work, most concerns arose from bystander perspectives, particularly regarding unauthorized recording without their awareness or consent [93]. Additionally, the absence of notifications for those being recorded intensifies these privacy concerns, affecting the adoption of technologies in public [132]. However, we found that both immersive headset users and bystanders were caught off-guard by the real-time immersive tracking experience.

Our work showed that despite being situated in a setting where observation by fellow passengers is customary, the introduction of asymmetric experiences adds an element of unexpectedness, which became distinctly evident in participants' real-life interactions. While prior work highlighted the need for reality-aware immersive headsets [49, 92] for enhancing safety and enjoyment of the virtual experience, we found that, in reality, users were surprised by such capabilities when engaged in asymmetric experiences. Some of the non-headset users felt they were being anonymous with their actions (G4, P12, M) and did not anticipate the shift in power dynamics. Immersive headset users also had negative initial reactions, with some feeling their actions were "rude" towards other passengers. This highlights the vital insights to be gained from *in situ* studies that allow participants to experience immersive tracking firsthand.

Upon further discussion, we observed an overall positive outlook toward body tracking for addressing physical safety concerns. Participants valued enhancing their awareness of surrounding activities, such as movements or presence of others. The need for additional social cues to adhere to social norms and support complex or extended interactions among passengers also became evident. This would, however, require collecting even more data about users and other passengers, such as gaze, expression, mood and state. This is likely within the capability of future headsets, as they are already able to collect audio, and camera inputs from users [2]. To support asymmetric experiences in transit settings, further work is needed to understand how future immersive technologies can provide tracking whilst remaining privacy-preserving. Potential solutions could include tracking only certain parts of the human body at a certain proximity and notifying the observed passengers accordingly.

5.4 Altered Behaviors During Interpersonal Interactions

Our findings suggest that the adoption of immersive technologies may influence changes in interpersonal interactions and norms of behavior among passengers. For example, this can involve adjusting approaches to initiating interactions or navigating around other passengers wearing immersive headsets. The impact of immersive technology on our behaviors is not an intentional design decision, but it does raise the question of whether designers should intentionally shape these effects. This prompts exploration into the potential of these technologies to influence users, given they can gather extensive physical and emotional user data [1, 32, 46, 47, 101, 120] over prolonged periods [93], enabling opportunities for tailored customization. The practice of influencing users' behaviors through recommendations, suggestions, or the design of the interface, often referred to as 'nudging', has already found applications in healthcare [124] environmental attitudes [110], and entertainment [11]. Immersive experiences could also be designed to create pro-social [82] experiences that shape behaviors to alleviate discomfort created by asymmetric passenger experiences. This might be achieved by increasing awareness of other passengers' activities or suggesting social ice-breakers and incentives to enhance passenger interaction.

However, the capacity to curate experiences based on user data raises important questions about the impact, purpose, and ethics of 'nudging' through immersive technologies. Could tailored experiences establish new social norms within environments where immersive technologies are used? Should we allow immersive technologies to influence interpersonal interaction, which could compromise user autonomy? As we navigate the transition into asymmetric multi-user experiences, ethical considerations must also come to the forefront. It is paramount to balance the effects of curated experiences that support passenger interactions and ethical considerations, highlighting the need for proactive dialogues on privacy safeguards, user consent, and responsible data usage. While the potential to reshape behaviors holds promise in addressing certain challenges tied to passenger interactions, it remains essential that ethical guidelines guide these transformations, ensuring immersive technologies support users and bystanders.

5.5 Breaking Research Gaps with Speculative Enactments

Speculative enactments proved to be a powerful method for exploring future transit scenarios involving asymmetric passenger experiences. Enactments enabled the simulation of social dynamics between users of disparate devices in situations that are starting to occur in real world settings but are not yet common. We uncovered that there is nuance to the unexpected interactions between passengers, with varying degrees of passenger engagement (passive, active, and reactive) and types of interaction (verbal and non-verbal) influencing the acceptance of immersive technologies. This level of detailed insight could not have been achieved in a traditional lab study, as enactments offer a unique perspective by enabling individuals to experience and 'enact' the unexpected interactions with other passengers. Additionally, we observed that asymmetric experiences contribute to a sense of unapproachability among passengers. The disconnect between users at different ends of the reality spectrum became evident through the enactments, which required participants to actually converse and discover where communication broke down. Furthermore, we found that participants were surprised by being tracked with immersive headsets, which revealed unanticipated shifts in power dynamics. Despite 'enacting' a setting where observation by fellow passengers is customary, the introduction of asymmetric experiences added an element of unexpectedness, distinctly evident in participants' real-life interactions. It would be difficult to uncover these power shifts with conventional methods, as they do not require participants to embody specific personas and confront preconceived expectations about those roles in real-time interactions.

These findings are critical for designing technologies that support user interactions across a range of disparate devices, which is needed to advance the acceptance of immersive technologies in transit. Speculative enactments made it possible to create the experience of this possible future, include a range of devices across the reality/virtuality continuum, and 'enact' the social interactions this research aimed to explore. Looking ahead, speculative enactments hold significant potential for future research, offering several strengths and some weaknesses. The method is particularly suitable for exploratory topics that depend on complex social contexts and where emerging technologies are not yet available or feasible to deploy in real settings. By simulating these interactions in a controlled environment, speculative enactments provide valuable qualitative data and address gaps in conventional research. However, there are challenges to consider. Effectively embodying a persona can be demanding, and participants' ability to fully immerse themselves in the scenario can vary, which may influence the consistency of the data. Additionally, enactments require significant time and depend on a crafted narrative, which can limit the range of scenarios explored. For studies requiring precise measurements and multiple variations of conditions, enactments may not be as effective. Despite these challenges, the strengths of speculative enactments in simulating real-world interactions make them a valuable tool for future research. In contexts where social dynamics are less critical, traditional methods such as lab studies can provide complementary insights, enhancing the overall understanding of future scenarios and emerging technologies.

6 LIMITATIONS

There are several experimental design and technical limitations in our study that must be acknowledged when interpreting our findings. First, our experimental approach involved enactments to recreate a single transit scenario, recognizing that it cannot fully capture the diversity of all possible scenarios and varying social settings. Enactments offer valuable insights in exploring potential futures [53, 59, 89, 90, 105] and can effectively create contexts for authentic social interactions [27]. Although we dedicated effort to enhancing interaction authenticity through warm-up exercises, it is important to recognize that the study was conducted within a controlled lab setting, where the use of enactments inherently shapes participant experiences and cannot fully replace real-world studies. These may yield different and novel insights and should be pursued in follow-up research. Second, our participants were tasked with a static activity—watching a documentary, a deliberate choice to minimize the introduction of confounding variables. However, the application of different task types, such as gaming or work-related activities, might result in varied passenger interactions and require exploration. Third, our selected visual representation of the anchors, although largely effective, could be improved to convey a wider range of social cues necessary for interactions that require complex or extended user involvement. While the study focused on visual cues, this was primarily because immersive headsets inherently occlude much of the user's visual field. Future work could expand on this approach by incorporating audio techniques to further enhance passenger awareness and help facilitate social interactions between passengers. Finally, the potential interactions among participants were influenced by technical considerations arising from the capabilities of the tracking cameras. We designed interaction scenarios to utilize current tracking capabilities, thereby creating a realistic range of interactions among passengers. As further improvements in simultaneous multi-body tracking occur, future research could explore a broader range of interactions, such as studying dynamics amongst large groups of passengers.

7 CONCLUSIONS

We presented an enactment study investigating asymmetric passenger experiences between users simultaneously using devices with varying levels of immersion, environmental information, and interactive abilities. Our use of novel enactments of a future scenario marks our first contribution (1). The study's findings demonstrate that engagement level and the nature of the interaction influence the acceptance of immersive technology in transit, marking our second contribution (2). Additionally, we showed that asymmetric experiences can create a sense of disconnection among passengers, especially for users at the opposing ends of the reality/virtuality spectrum, marking our third contribution (3). Finally, we validate the use of VR headsets with Reality Anchors, finding that immersive tracking reduces physical safety concerns but requires further refinement to support interactions that require active user involvement, marking our fourth contribution (4). Our work represents an important first step towards understanding the dynamics of asymmetric passenger experiences in transit.

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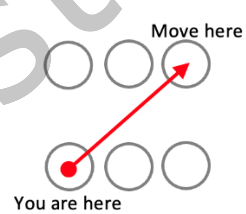
A APPENDIX. INTERVIEW GUIDE.

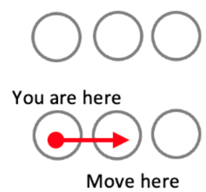
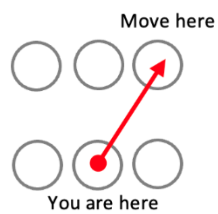
[Topic: Introductions]

5. Welcome to the focus group! Before we begin, can each of you introduce yourself, mentioning which persona you portrayed during the experiment?
   (Allow participants to introduce themselves, ask to always mention their persona when speaking, then move on to the next question)
6. [For all] What were your initial reactions to the scenario you just experienced in the experiment?
   ("Can you tell us more about that?" or "What specifically stood out to you?")
   [Topic: Perception of Interaction]
7. [For all] How did you feel about the interaction you were required to complete during the experiment?
8. [For mobile] When you were performing (moving/dropping pens/asking a question), how did you feel? Did you have any concerns?
9. [For VR user] When you were performing (asking a question/moving), how did you feel? Did you have any concerns?
10. [For VR+ RA user] When you were asking the questions, how did you feel? Did you have any concerns?
11. [For VR + RA & Mobile users] When you were observing (change based on persona) how did you feel? Did you have any concerns?
12. [For VR user] Did you notice anything happening around you? What stood out to you? Did you have any concerns?
13. [For all] Were there any surprises or unexpected moments?
    ("What did you think of the other participants' interactions?" or "When you were observing that, what did you think?")
    [Topic: Social Acceptability]
14. What does the term "social acceptability" mean to you?
    In our research, we describe technology as being socially acceptable when it can be used/worn around others without feeling uncomfortable, out of place or judged and where other people around the user also do not feel uncomfortable.
15. Now that you have heard this definition, how socially acceptable or not acceptable do you think was this experience? Let's discuss in more detail.
16. [For mobile user] When you had to move to a different seat, stretch and drop the pens did, you think it was socially acceptable or unacceptable? How would you feel about the interaction if your role was VR user/ Reality Anchors user?
17. When you were asked a question by the VR user/VR + Reality Anchors user/ saw a VR user moving, did you think their actions were socially acceptable or unacceptable?
18. [For VR user] When you had to ask a question and move seats, did you think it was socially acceptable or unacceptable? How would you feel about the interaction if your role was a mobile user/ Reality Anchors user?
19. When you were asked a question by the Reality Anchors user, did you think their action was socially acceptable or unacceptable?

20. Did you notice any other actions happening around you? Did you think they were socially acceptable or unacceptable?
21. [For Reality Anchors User] You had to ask a couple of questions. Did you think it was socially acceptable or unacceptable? How would you feel about the interaction if your role was a mobile user/ VR user?
22. Did you notice any other actions happening around you? Did you think they were socially acceptable or unacceptable?
    (“When you saw other passengers moving around/asking questions, did you think their actions were socially acceptable or unacceptable?”)
    ("What makes you say that?" or "Can you explain more?")
    [Topic: Using Reality Anchors]
23. [For all] How did you feel about the VR headset with cues from reality?
24. [For observers] Does knowing that the VR + Reality Anchors user could see you change how you feel about the interaction you completed? Did you realise you were being seen?
    ("What did you think of the Reality Anchors?" or, for observers, "Would you have acted differently if you were using a headset with the Reality Anchors?")
25. [For all] How would you feel about using a headset with the cues enabled in a real travelling context? For example, a daily commute, or a long-haul trip?
26. [For all] Would the mode of transport influence your feelings about using the headset with Reality Anchors?
    ("Why is that?" or "Can you tell us more about your thoughts on that?")
27. [For all] Is there anything else that you would like to mention before we wrap up?
28. [For all] Any final questions or comments?
    (Allow each participant to answer, then conclude the focus group).

B APPENDIX. LIST OF PROMPTS.

User	Time	Prompt
Mobile	2.5 min	1. Please stand up; 2. Do some stretches; 3. Move over here: 
	7 min	1. Please move over here:

User	Time	Prompt
		 2. Please drop your bag with pens.
VR	4.5 min	1. Please ask a person to your left a question: “Could you tell me what is the final destination for this train?” 2. Please remove your headset and move over here: 
	9 min	Please take off the headset and leave the chair area.
XR	6 min	Please ask the person in front of you, "So, what are your plans in Edinburgh?"
	9 min	Please turn to the person on your left and ask them: “Could you tell me what time it is?”

C PARTICIPANT DEMOGRAPHICS.

Session	P #	Gender	Age	Occupation	Experience with VR	Device	Frequency*	Familiar with other participants?
1	1	M	22	Student	Yes	VR	Regularly	No
1	2	M	33	Student	Yes	XR	Infrequently	No
1	3	F	28	Student	Yes	Mobile	Infrequently	No
2	4	F	18	Student	Yes	VR	Once	No
2	5	M	32	Student	No	XR	N/A	No
2	6	F	42	Student	No	Mobile	N/A	No
3	7	M	26	Student	Yes	VR	Frequently	Yes, participant 8
3	8	M	30	Researcher	Yes	XR	Frequently	Yes, participant 7
3	9	F	23	Student	Yes	Mobile	Once	No
4	10	F	42	Student	No	VR	N/A	Yes, participant 11
4	11	F	29	Student	No	XR	N/A	Yes, participant 10
4	12	M	35	Student	Yes	Mobile	Infrequently	No
5	13	M	37	Student	Yes	VR	Once	No
5	14	M	44	Student	No	XR	N/A	No
5	15	F	51	Administrator	Yes	Mobile	Infrequently	No
6	16	M	23	Researcher	Yes	VR	Frequently	No
6	17	F	37	Researcher	Yes	XR	Once	No
6	18	M	33	Student	Yes	Mobile	Infrequently	No
7	19	M	24	Student	Yes	VR	Frequently	Yes, participant 21
7	20	M	42	Researcher	Yes	XR	Once	No
7	21	M	24	Student	Yes	Mobile	Frequently	Yes, participant 19