In-cAR Gaming: Exploring the use of AR headsets to Leverage Passenger Travel Environments for Mixed Reality Gameplay

Henry Togwell
School of Computing Science,
University of Glasgow
Glasgow, UK

Mark McGill
Mark.McGill@glasgow.ac.uk
School of Computing Science,
University of Glasgow
Glasgow, UK

Graham Wilson
Graham.Wilson@glasgow.ac.uk
School of Computing Science,
University of Glasgow
Glasgow, UK

Daniel Medeiros
Daniel.PiresdeSaMedeiros@glasgow.ac.uk
School of Computing Science,
University of Glasgow
Glasgow, UK

Stephen Brewster
Stephen.Brewster@glasgow.ac.uk
School of Computing Science,
University of Glasgow
Glasgow, UK

ABSTRACT

Autonomous cars offer passengers a rich platform for Augmented Reality entertainment, with complex sensing that can drive passenger experiences by tracking, appropriating and altering elements of reality. This paper forms an early exploration of in-car AR games, starting with how existing game genres might work within an AR vehicle context, appropriating elements of reality (e.g. other cars) into gameplay, and altering the appearance of reality in relation to game events (e.g. augmented cracks in car windows). We discuss results from focus groups exploring an initial AR game prototype, and an informal in-car evaluation of a follow-up prototype inspired by the focus groups. Broadly, we found that participants enjoyed using AR gaming in-car, noted the immersive impact of appropriating real-world elements into gameplay, and felt that it improved their experience of the journey. We reflect on the ways in which future AR passenger experiences might take advantage of the available sensing and environment to create engaging reality-based gameplay.

CCS CONCEPTS

• **Human-centered computing** → **Mixed / augmented reality**.

KEYWORDS

Augmented Reality; Extended Reality; Gaming; Passengers; In-Car; Automotive.

ACM Reference Format:
Henry Togwell, Mark McGill, Graham Wilson, Daniel Medeiros, and Stephen Brewster. 2022. In-cAR Gaming: Exploring the use of AR headsets to Leverage Passenger Travel Environments for Mixed Reality Gameplay. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI '22 Extended Abstracts), April 29-May 5, 2022, New Orleans, LA, USA.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3491101.3519741

CHI '22 Extended Abstracts, April 29-May 5, 2022, New Orleans, LA, USA

ACM ISBN 978-1-4503-9156-6/22/04…$15.00
https://doi.org/10.1145/3491101.3519741

1 INTRODUCTION

The advent of autonomous vehicles means that passengers will have more free time for leisure activities when travelling (e.g., [12, 17, 25]), including playing games. However, motion sickness can make it impossible for many people to engage in activities that divert visual attention away from the motion of the outside world, such as reading, smartphones or, more recently, Virtual Reality (VR) headsets [18]. Augmented Reality (AR), where digital objects are overlaid onto a view of the real world via Head-Mounted Displays (HMDs), could let passengers play games while providing them with a clear view of the car and its surroundings. AR games could also leverage location-based or reality-based information - such as a route, other cars or buildings - that is gathered by sensing technology within autonomous cars (e.g., LiDAR and GNSS). This could lead to more engaging travel experiences, increase the player's connection to their local area [13], or let those who get motion sick play games comfortably. However, little is known about how to design AR-based games for car passengers, such as if and how to appropriate the car and outside world into the game, what genres of game would be best suited to play in a car cabin, and what aspects of game design provide a good player experience. Therefore, this late-breaking work contains an initial investigation into how we might exploit the combination of AR HMDs and vehicle-based sensing of reality to create AR games and potentially improve the travel experience. We first explored how different genres of game might take advantage of vehicular AR for reality-based gameplay through focus groups and an "endless runner" [35] game prototype. From the results, we created a prototype "zombie horde survival" game to explore the strengths and weaknesses of our design through an in-car think-aloud evaluation. Broadly, we reflect on opportunities afforded by the in-car AR game design space for facilitating reality-based passenger experiences.

2 BACKGROUND

2.1 In-Car XR

Many car manufacturers provide simple augmented reality displays in their vehicles. Ford, Mazda and Mini sell models with Head Up Displays (HUD) [20], a form of vehicle-integrated AR where the driver can see the road ahead with information such as their speed overlaid onto it. Hardware requirements mean they are typically small with limited display area, which inhibits both the amount and type of information they can convey. Additionally, they are in a fixed position and so cannot be used by passengers. Companies like WayRay [37] are expanding on this by creating full AR windscreens. However, this technology is not yet widely available, with such displays having notable limitations in terms of facilitating personal 3D perspective correct AR experiences [6]. Conversely, AR HMDs as worn by a passenger could enable personal 3D AR experiences, if sufficient access to vehicle sensing is provided. Haeuslschmid *et al.* [10] and Wiegand *et al.* [39] set out design spaces for in-car AR experiences on the windshield and the vehicle interior, respectively, but the technology has largely been focused on supporting the driver [24], particularly for navigation or for improving the driver's awareness of hazards [33] such as the intended actions of autonomous cars [27] or rendering other cars transparent to show occluded objects behind [34]. Research has also looked at the use of VR approaches to entertain passengers in vehicles. In particular, Holoride [12] and CarVR [11] use a vehicle's navigation and environment data to match VR experiences to the physical movements of the car. Other research has looked at in-car VR for driving simulations [8, 9], productivity [16] and mindfulness [23], as well as explored wider issues such as social acceptability [40], and the challenges faced in facilitating correct operation of in-car XR [18]. However, VR applications do not tend to appropriate or augment reality, instead using the immersiveness of VR to construct alternative virtual worlds.

2.2 Gamification of AR

Unlike digital games, AR games can appropriate elements of the physical world around players into gameplay, as highlighted by Wetzel *et al.* [38] who outline a list of guidelines to consider while creating an AR game, including the need to incorporate physical objects into the game. Oda *et al.* [22] created a driving game where the physical world was an essential part of gameplay: a virtual car raced around a track built from blocks placed in the real world. Nintendo's Mario Kart Live: Home Circuit [19] uses an on-board camera to let players see virtual tracks and rivals from a toy kart's perspective. Aultman *et al.* [1] provided design heuristics for AR game UIs, including the placement of UI elements next to real objects, making the UI distinct from the real world, and matching the UI to the user's viewing angle. Dillman *et al.* [4] describe a framework for designing AR visual cues to inform game players about objects or locations of interest, recommending approaches such as object-aligned visual highlights as well as arrows or maps.

Our paper is a first step into the design of AR games for in-car passenger spaces. Because of the physical constraints of car cabins, the unique affordances/limitations of visible real-world objects, and limited variety of commercial AR games, it is not clear how people would want to play AR games in cars. To start exploring the issue, we created a prototype incorporating nearby vehicles into gameplay. We presented this prototype, along with other potential game designs, in focus groups to gather ideas and feedback to inform a wider understanding of AR gaming in-car, and design a second prototype prior to in-car testing. Based on this, we reflect on how the affordances of the journey might contribute to AR gameplay, and discuss challenges and opportunities in transposing existing genres to in-cAR.

3 GAME PROTOTYPE ONE - ENDLESS RUNNER

3.1 Game Design

We designed the game experience for passengers in a front car seat, allowing players to see cars in front of them, and using the road ahead to appropriate for gameplay. For this initial exploration, we utilised a well-known and simple gameplay mechanic: the "endless runner" style game, similar to popular mobile apps such as Temple Run [31] or Subway Surfers [14]. In the prototype, the player controlled a car avatar that was displayed as if located on the road in front of the passenger, and moved the car using head orientation tracking via a pair of NReal AR Glasses (see Section 3.2). Players had to dodge both physical obstacles (other real cars on the road) as well as virtual obstacles (bombs) placed in the road, and collect coins to increase their score. Hitting obstacles would reset the score to zero.

3.2 Hardware Implementation

To emulate LiDAR-like sensing of autonomous vehicles' external environment, we used a ZED 2 stereo camera [30], which has a 120° wide angle field of view ahead of the car, mounted at the centre of the dashboard. For the display we used the NReal AR Glasses [21], which run Android and feature a 1080P resolution, 52° field of view, and 6 Degrees of Freedom tracking. A laptop ran a Unity project that took input from the ZED 2 camera and used its API to recognise vehicles automatically. A second Unity project ran on the NReal glasses to detect player input via head movement and to display the game to the player. The two Unity programs communicated via the Unity Low Level Network API over a laptop Wi-Fi hotspot. The sizes, positions and IDs of the detected vehicles were sent (via JSON) across the network to the glasses to augment the vehicles as appropriate. The finished design of prototype one can be seen in Figure 1. Due to COVID-19 restrictions, the onus of this prototype was to provide participants in remote focus groups with an example AR game that appropriated elements of reality into gameplay, a key component of AR gaming [36]. In doing so, this would help participants understand and explore AR gaming concepts and provide opinions on them.

4 FOCUS GROUP EVALUATION

The game prototype was evaluated through three online focus groups, which were divided into two activities:

Demonstration of prototype: Videos and composite images were shown to demonstrate the game prototype and an experimenter explained the game features. We then showed two examples illustrating other AR gameplay concepts that appropriated

Figure 1: Game Prototype One (L), and example concept prompts shown in focus groups to illustrate gameplay in different car perspectives: a virtual car avoids real and virtual obstacles visible out the windscreen (M) and a platform game through a side window, jumping over bus stops to collect coins (R).

elements of reality from different perspectives: controlling a virtual car ahead out the windscreen, and platforming on real surfaces out a side window (see Figure 1).

Genre and perspective concepts: The experimenter presented a slideshow of different game genres to act as prompts and asked participants how they might apply each genre to in-car AR: platforming, racing, simulators for other modes of transit (e.g. trucks, planes), puzzles, and action games. For each genre, players were asked to give suggestions and discuss ideas for gameplay when the player is facing forward (looking out the windscreen) and sideways (looking out a side window) to explore if certain game types were seen as better suited to different positions.

Focus groups were conducted over Zoom and were recorded and qualitatively analysed to identify common themes, sentiments or suggestions, through descriptive and *in vivo* coding [26]. After the focus group, each participant completed a short questionnaire regarding how often they played video games and their previous use of Augmented Reality.

Eight participants took part across three focus groups. Five participants had experience of using smartphone-based AR, including three who had played AR games such as Pokémon Go. The remaining three participants were aware of AR but had not used it. Three participants played games multiple times a week, two played once a week, and three played less than once a week, giving a broad range of gaming experience.

4.1 Results

Platform Games. All groups highlighted the concept of the player jumping on the edges of real objects as their favourite aspect, appropriating reality in a familiar way (e.g., [2]). Participants agreed that looking out a side window would work best, as the movement of the car would be part of gameplay. They acknowledged that heavy traffic would adversely affect this, but that virtual obstacles could increase the challenge and reduce the impact of the car stopping.

Puzzle Games. The concept of playing a Tetris-style game using other cars was raised, where the player would slot shapes between nearby vehicles to gain points. Two groups suggested the idea of having a list of objects which players needed to spot, be they real items or virtual objects hidden in the environment around the car.

Action Games. The action genre received a lot of discussion. Participants liked the idea of having a virtual weapon to shoot at other vehicles on the road for points. 'Power-ups' (gameplay bonuses to improve player attributes) could be added to gain extra abilities, similar to popular games such as Nintendo's Mario Kart. Participants also raised the idea of having pedestrians around the car represent enemies which need to be attacked virtually, although concerns were raised about potential ethical and privacy ramifications. The idea was then reworked into having virtual enemies approach the player's car which then needed to be defended by the player. Participants thought this would be an exciting game but noted that a strong connection to the physical world would improve it significantly.

Areas to Avoid. Some genres of game were considered to be potentially unsuitable for in-car AR play. It was suggested that vehicle simulation games would not be as entertaining, as it may be too similar to the real driving scenario. Strategy games may require a level of detail and control which would be difficult to achieve in the AR setup that was presented to participants. Racing games were discussed by participants, but they were dissuaded by the fact that the player does not have control of their car's movement (unlike suggested in [9, 18]).

5 GAME PROTOTYPE TWO - ZOMBIE SURVIVAL

While participants in the focus groups appreciated the first game prototype as a proof of concept, it was important to explore real player experiences more deeply, to probe concrete game design choices and to test a real-world implementation. From the focus groups, the action genre garnered the most interest from participants, and the use of real-world objects in the game was important. Therefore, we developed a second game prototype - a zombie survival game loosely modelled on the popular VR game Arizona Sunshine [7].

5.1 Design and Implementation

We used the same hardware setup and communications method (Unity applications on laptop and AR glasses) as the first prototype. The player sat in the front passenger seat of a car, looking forward. Virtual zombies would spawn a distance from the car that made them visibly clear and targetable and would move towards the player, who controlled a virtual gun via the position and orientation of the NReal Glasses controller puck. When a zombie collider was hit with a virtual bullet from the gun, it would lose health and disappear, and the player would be awarded points. Zombies

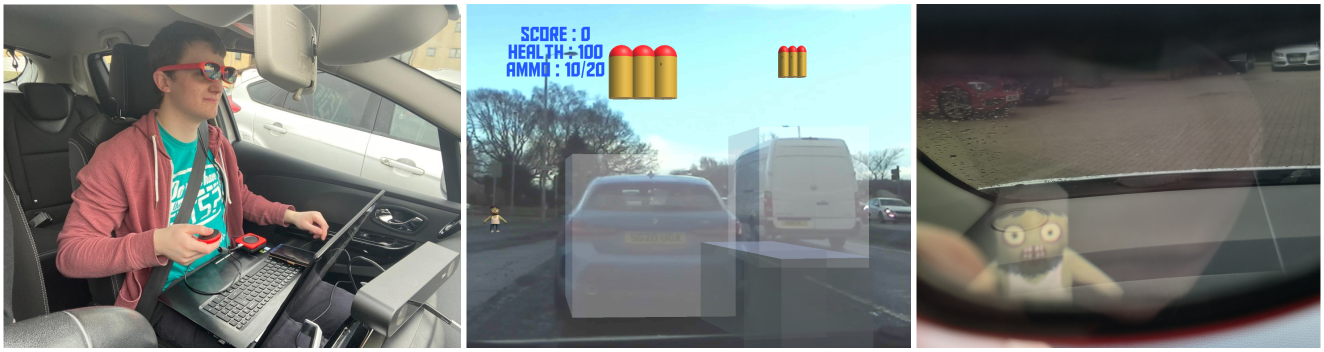

Figure 2: Game Prototype Two. Hardware setup, with ZED 2 on dashboard, AR glasses, server laptop and controller puck (L). Composite of AR view and captured video of journey illustrating experience (M). Zombie captured through the AR headset lens (R).

would only be spawned within the 120° gameplay area to avoid uncomfortable head and arm movements by players, and so the location/movement of zombies towards the player was always ahead of the car (i.e., they were not aligned with a specific object in reality). The player had three resources displayed to them, which could be increased by collecting 'power-ups': score, ammo (ammunition) and health. Based on the earlier focus groups, power-ups were dropped by shooting visible bounding boxes attached to other real-world vehicles around the player's car and these power-ups were shown via a virtual symbol displayed above the vehicle. When a vehicle is shot, the player collects the resource and the box overlay becomes cracked to indicate it has been destroyed. Integration with reality was also leveraged for the player's health, which is both represented by a number in the user interface, as well as overlaying virtual damage on the inside of the player's car, via a cracked, damage layer over the windows. Health was reduced when a zombie collider contacted a collider around the car and it remained there causing damage over time until either it was shot or the game ended. The car had a set amount of health which can only be restored through picking up power-ups. It was hypothesised that this design would add to the immersion and intensity of the experience as the player would be able to see their car being damaged in real time and would have to quickly find and stop the cause. When the player's health reaches zero, an end screen with the accumulated score is shown to support replayability. The user interface was displayed in a fixed exocentric location just above the horizon against the sky. The game ended when the player's health dropped to 0 and the final score was presented to the player. The finished design can be seen in Figure 2.

5.2 Demographics, Evaluation Design and Measures

The intention for this prototype was to conduct in-person evaluations in a real car. COVID-19 restrictions were still in place when testing was conducted, and so only four participants were recruited, University students aged 21-24 (2 female, 2 male) from within an authors' extended bubble. The number was limited but it was important to gather ecologically valid *in situ* player experiences. All four participants had heard of augmented reality as a technology before and were aware of what it was but had not used it. Each participant played multiple rounds of the game to ensure that they were able to experience it in its entirety and understand the game mechanics. For consistency, the same city roads with long straight stretches and speed limits between 48-60KPH were used. A think-aloud methodology was used [5], where participant were asked to verbalise their thoughts and feelings as they played in real-time, and audio recordings were later analysed for shared emerging themes, through descriptive and *in vivo* codes [26]. Participants played for 15 to 25 minutes including time to provide think aloud feedback and to reset/restart the game.

5.3 Think Aloud Results

5.3.1 In-Car AR.

Perspective. Two participants commented on how the passenger seating position gave them a good view of the road ahead, providing a wide area in which the game could be played. Another participant mentioned how they preferred the idea of looking forward while playing as it meant they would be less prone to car sickness from looking sideways continually. One remarked how the style of game would be unsuitable for those in the back seats.

Extended Reality. Participants greatly appreciated the exocentric scoreboard, as its static location in the sky made the game feel futuristic, and two said that if it followed the player's view like a traditional game, it would have lessened the immersion. It was also noted that having to look up to see the score and health added to the intensity of the game, as it was time spent not defending the car. These comments further support the importance of incorporating virtual elements into reality, both from an engagement/immersion perspective and a gameplay/attention perspective. Zombies growing larger as they moved towards the player was appreciated, as it felt unnerving, which fits the genre well and emphasises a potential benefit of using an AR HMD. And all participants noted that zombies moving relative to the player's car (i.e., not being aligned to locations in reality) did not negatively impact the experience.

Gameplay Area. Participants appreciated that zombies only spawned ahead of them, due to the seat/seat-belt restrictions, as it meant that they didn't need to be continually turning around to potentially uncomfortable positions. It was mentioned that this should be avoided as it could also potentially distract or interfere with the driver.

5.3.2 Game Design.

Altered Reality. The zombies causing virtual damage to be rendered onto the car was very popular. Participants repeatedly mentioned how they thought it significantly improved the game, that it added an extra level of intensity, as the threat of losing was made very clear. This clear goal of staying alive made the game much more engaging and it was said that without it, it could become boring and repetitive. A suggestion to improve this feature was a visual or auditory indicator of where damage was coming from, as sometimes it could be difficult to know where to look.

Player Entertainment. Broadly, participant reactions were highly positive, including a desire to play even when not travelling long journeys (i.e., a more 'everyday' activity), and suggesting that such a game could improve the general travel experience. It was suggested that the game would be enjoyable even if played at home, but that it would not be as good without the vehicle-specific AR features. All of the participants said they enjoyed using the AR technology.

Atmosphere. Most felt that the overall atmosphere of the game could be improved. It was said that it felt like it was aimed at children due to the cartoonish graphics. Participants suggested that more visual realism and additional spatialized sound effects could improve the intensity of the experience. Suggestions for this included zombie sounds and noises being made as the car was damaged as this would make stopping the attackers even more frantic.

5.3.3 Technical Factors.

Control. Most participants had issues with the alignment of the NReal controller, reporting that it would drift over time and make shooting difficult, especially when zombies approached from the side. Headsets with inside-out tracking optimised for a moving car environment would help solve this problem.

Clarity and AR Alignment. Zombies would sometimes pass through other vehicles and were not occluded correctly with respect to reality. This was confusing and broke some participants' immersion. Bright sunlight also made certain AR aspects difficult to see, especially vehicle outlines, which were also occasionally misaligned across sensing and AR reference frames. One participant was uncertain about whether they needed to shoot the symbol of the power-up or the outline of the vehicle itself, suggesting confusion regarding the integration of real and virtual.

6 DISCUSSION

6.1 Gameplay and Design

Participants in focus group one believed that action and platforming genres could be particularly well-suited to in-car AR games, as they could be played with simple controls from confined spaces and could make use of physical objects or surfaces visible through car windows. Across both focus groups, the opportunities and restrictions for gameplay were identified depending on the passengers seated position. While the ideal position might be in the front passenger seat, for a wide open view for augmenting reality, many passengers need to be in rear seats, and so games could instead make use of side views out the window for e.g., platform games, or use seat backs for display/input surfaces. The 120° play area in our prototypes was well-suited to the physical constraints of the front seat, seat belt and driver proximity when using motion controls. But robust sensing is needed to mitigate control inaccuracies during car motion, and bright sunlight can obscure virtual elements. Conversely, back-seat players may have more open lateral space in which to play. As suggested by Wetzel *et al.* [38] and Aultman *et al.* [1], it is important to integrate virtual objects with physical landmarks, such as game items attached to other cars, and integrate physical objects with virtual events (own car being attacked). Some of our results contradict recommendations for AR UI design in non-gaming contexts, as Aultman *et al.* suggest matching a UI to the user's viewing angle whereas participants enjoyed the exocentric horizon-linked UI in Prototype Game Two. Our early results hint that placing game elements around the visible scene can increase immersion by merging real and virtual, as well as affecting gameplay by dividing player attention. However, players may be willing to accept mismatched interactions between real and virtual elements (e.g., zombies moving relative to car) if the design/mechanic supports a more comfortable or enjoyable experience.

6.2 Affordances and Appropriation

If we refer to Schraffenberger's taxonomy of AR experiences [28], what we have demonstrated in our designs covers both *extended reality* (the virtual supplements the real - power-ups attached to vehicles) and *altered reality* (the virtual transforms the real - augmenting vehicles with damage). More broadly, we propose novel opportunities for appropriating the affordances of a given journey for AR gaming, much as SoundsRide appropriated them for music [13], which we present in Table 1. The combination of an AR HMD backed by vehicle-based sensing provides significant scope for imagination and innovation in the use of AR gaming to enhance passenger journeys.

From this paper's initial findings, there are many possible research avenues: What makes a game well-suited to merging real and virtual? What game elements can or should be attached to real-world objects? How can additional player/car sensing offer more options for game design? What is the best balance of real vs virtual content? The answer to these questions, and the perceived utility and enjoyability of AR gaming, is also likely to vary significantly across genres, with each genre likely to pose unique opportunities, but also challenges. For example, the ever changing makeup of the external environment outside the vehicle, and the vastly different urban environments around the world [32], complicates appropriation and maintaining theme consistency between real and virtual. However, assuming underlying technology challenges (e.g. motion sickness and alignment issues [18], pedestrian privacy [3] etc.) can be overcome, our work outlines that there is significant promise in facilitating AR reality-based gameplay for passengers.

Journey Artefact / Affordance	Varying Factors	Example Use(s) in AR: Extended Reality *Virtual Supplements Real*	Example Use(s) in AR: Altered Reality *Virtual Transforms Real*
Passenger's vehicle	Seating position/perspective, physical surfaces, motion [18]	Appropriating available surfaces e.g., seatback for input	Substitutional reality [29] to change appearance of car
Other vehicles	Public info e.g., type (car, bike, van), make, colour, number plate, movement; private info for known vehicles e.g., destination, passengers	Attaching unique gameplay elements to artefact (e.g. power-ups)	Visualizing impact of game (e.g. damage)
Environment	Lighting, background, locale (city, country, forest etc.)	Rendering new virtual artefacts that realistically inhabit the real environment (e.g. zombies lit appropriately)	Altering perception of sky to create atmosphere [41]
Environment-specific artefacts	Physical infrastructure (buildings, signs, lights, pylons); Natural elements (animals, trees)	Appropriating detected edges for platformer gameplay or enemy spawns	Modifying appearance of buildings to fit gameplay aesthetic
Multiplayer	Players in: same vehicle; nearby vehicles (e.g., [15]); remote vehicles; A/synchronous gameplay.	Incorporate awareness of other player's actions, location-based events; render remote players locally	Visualize or alter appearance of other players and/or their vehicles
Journey / Contextual knowledge	Duration, route taken, foreknowledge of vehicle actions (e.g. upcoming stops), world location	Visualise enemies on route ahead; gameplay changes based on salient locations (e.g. new enemies in tunnel)	Virtual artefacts related to world location (e.g. render ancient Roman city over open field)

Table 1: Examples of affordances of passenger experience that could be utilized for in-car passenger AR gaming.

7 CONCLUSION

This paper has examined the utility of combining passenger usage of AR HMDs for gaming with the sensing capability of typical autonomous and semi-autonomous vehicles - facilitating AR gaming that can appropriate elements of reality into gameplay. Our initial results have shown that in-vehicle AR gaming provides a new space for game design and play. We demonstrated how incorporating nearby vehicles into gameplay could create more engaging experiences and allow unique gaming opportunities. We also showed how augmenting both the passenger's vehicle, and other vehicles on the road, based on game events could enhance immersion. Informed by this, we have provided a number of avenues for future research, by which AR passenger experiences might take advantage of the affordances of a journey.

ACKNOWLEDGMENTS

This research received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (#835197, *ViAjeRo*).

REFERENCES

[1] Andrew Aultman, Spencer Dowie, and Nelly Ann Hamid. 2018. Design Heuristics for Mobile Augmented Reality Game User Interfaces. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI EA '18)*. Association for Computing Machinery, New York, NY, USA, 1–5. https://doi.org/10.1145/3170427.3188580

[2] Alexander Baldwin, Jeanette Eriksson, and Carl Magnus Olsson. 2017. Bus Runner: Using Contextual Cues for Procedural Generation of Game Content on Public Transport. In *HCI*. 21–34. https://doi.org/10.1007/978-3-319-58077-7_2

[3] Cara Bloom, Joshua Tan, Javed Ramjohn, and Lujo Bauer. 2017. Self-driving cars and data collection: Privacy perceptions of networked autonomous vehicles. In *Thirteenth Symposium on Usable Privacy and Security ({SOUPS} 2017)*. 357–375.

[4] Kody R. Dillman, Terrance Tin Hoi Mok, Anthony Tang, Lora Oehlberg, and Alex Mitchell. 2018. *A Visual Interaction Cue Framework from Video Game Environments for Augmented Reality*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3173574.3173714

[5] K.A. Ericsson and H.A. Simon. 1993. *Protocol Analysis: Verbal Reports as Data (Rev Ed.)*. The MIT Press.

[6] Joseph L. Gabbard, Gregory M. Fitch, and Hyungil Kim. 2014. Behind the Glass: Driver Challenges and Opportunities for AR Automotive Applications. *Proc. IEEE* 102, 2 (2014), 124–136. https://doi.org/10.1109/JPROC.2013.2294642

[7] Vertigo Games and Jaywalkers Interactive. 2021. *Arizona Sunshine*. https://arizona-sunshine.com/

[8] David Goedicke, Alexandra W.D. Bremers, Hiroshi Yasuda, and Wendy Ju. 2021. *XR-OOM: Mixing Virtual Driving Simulation with Real Cars and Environments Safely*. Association for Computing Machinery, New York, NY, USA, 67–70. https://doi.org/10.1145/3473682.3480266

[9] David Goedicke, Jamy Li, Vanessa Evers, and Wendy Ju. 2018. VR-OOM: Virtual Reality On-ROad Driving SiMulation. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3173574.3173739

[10] Renate Haeuslschmid, Bastian Pfleging, and Florian Alt. 2016. A Design Space to Support the Development of Windshield Applications for the Car. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 5076–5091. https://doi.org/10.1145/2858036.2858336

[11] Philipp Hock, Sebastian Benedikter, Jan Gugenheimer, and Enrico Rukzio. 2017. CarVR: Enabling In-Car Virtual Reality Entertainment. 4034–4044. https://doi.org/10.1145/3025453.3025665

[12] Holoride. 2021. *Turning vehicles into moving theme parks*. https://www.holoride.com/

[13] Mohamed Kari, Tobias Grosse-Puppendahl, Alexander Jagaciak, David Bethge, Reinhard Schütte, and Christian Holz. 2021. SoundsRide: Affordance-Synchronized Music Mixing for In-Car Audio Augmented Reality. 118–133. https://doi.org/10.1145/3472749.3474739

[14] Kiloo. 2021. *Subway Surfers Mobile Game*. https://www.kiloo.com/subway-surfers/

[15] Matthew Lakier, Lennart E. Nacke, Takeo Igarashi, and Daniel Vogel. 2019. Cross-Car, Multiplayer Games for Semi-Autonomous Driving. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (Barcelona, Spain) *(CHI PLAY '19)*. Association for Computing Machinery, New York, NY, USA, 467–480. https://doi.org/10.1145/3311350.3347166

[16] Jingyi Li, Ceenu George, Andrea Ngao, Kai Holländer, Stefan Mayer, and Andreas Butz. 2020. An Exploration of Users' Thoughts on Rear-Seat Productivity in Virtual Reality. In *12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Virtual Event, DC, USA) *(AutomotiveUI '20)*. Association for Computing Machinery, New York, NY, USA, 92–95. https://doi.org/10.1145/3409251.3411732

[17] Ford Global Technologies LLC. 2016. *Autonomous Vehicle Entertainment System*. Patent US9272708B2.

[18] Mark McGill, Julie Williamson, Alexander Ng, Frank Pollick, and Stephen Brewster. 2019. Challenges in passenger use of mixed reality headsets in cars and other transportation. *Virtual Reality* 24, 4 (2019), 583–603. https://doi.org/10.1007/s10055-019-00420-x

[19] Nintendo. 2021. *Mario Kart Live: Home Circuit*. https://www.nintendo.co.uk/Games/Nintendo-Switch-download-software/Mario-Kart-Live-Home-Circuit-1832413.html

[20] Brian Normile. 2020. *Which Cars Have Head-Up Displays for 2020?* https://www.cars.com/articles/which-cars-have-head-up-displays-for-2020-421615/

[21] NReal. 2020. *NReal Light AR Glasses*. https://www.nreal.ai/

[22] Ohan Oda, Levi J. Lister, Sean White, and Steven Feiner. 2008. Developing an Augmented Reality Racing Game. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering).

[23] Pablo E. Paredes, Stephanie Balters, Kyle Qian, Elizabeth L. Murnane, Francisco Ordóñez, Wendy Ju, and James A. Landay. 2018. Driving with the Fishes: Towards Calming and Mindful Virtual Reality Experiences for the Car. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 2, 4, Article 184 (Dec. 2018), 21 pages. https://doi.org/10.1145/3287062

[24] Annie Pauzie. 2015. Head Up Display in Automotive: A New Reality for the Driver. In *Design, User Experience, and Usability: Interactive Experience Design*, Aaron Marcus (Ed.). Springer International Publishing, Cham, 505–516.

[25] Rinspeed. 2014. *Rinspeed XCHANGE.* https://www.rinspeed.eu/en/XchangE_24_concept-car.html

[26] Johnny Saldaña. 2015. *The Coding Manual for Qualitative Researchers.* SAGE Publications.

[27] Nadja Schomig, Katharina Wiedemann, Frederik Naujoks, Alexandra Neukum, Bettina Leuchtenberg, and Thomas Vohringer-Kuhnt. 2018. An Augmented Reality Display for Conditionally Automated Driving. *Adjunct Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (2018). https://doi.org/10.1145/3239092.3265956

[28] Hanna Kathrin Schraffenberger. 2018. *Arguably augmented reality: relationships between the virtual and the real.* Ph. D. Dissertation. Leiden Institute of Advanced Computer Science (LIACS). https://openaccess.leidenuniv.nl/handle/1887/67292

[29] Adalberto L. Simeone, Eduardo Velloso, and Hans Gellersen. 2015. Substitutional Reality: Using the Physical Environment to Design Virtual Reality Experiences. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 3307–3316. https://doi.org/10.1145/2702123.2702389

[30] Stereolabs. 2020. *A Next-generation Stereo Camera.* https://www.stereolabs.com/zed-2/

[31] Imangi Studios. 2021. *Temple Run Mobile Game.* https://play.google.com/store/apps/details?id=com.imangi.templerun

[32] Jason Thompson, Mark Stevenson, Jasper S Wijnands, Kerry A Nice, Gideon DPA Aschwanden, Jeremy Silver, Mark Nieuwenhuijsen, Peter Rayner, Robyn Schofield, Rohit Hariharan, and Christopher N Morrison. 2020. A global analysis of urban design types and road transport injury: an image processing study. *Lancet Planet Health* 4 (2020), 32–42. https://doi.org/10.1016/S2542-5196(19)30263-3

[33] M. Tonnis, C. Sandor, G. Klinker, C. Lange, and H. Bubb. 2005. Experimental evaluation of an augmented reality visualization for directing a car driver's attention. *Fourth IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR'05)* (2005). https://doi.org/10.1109/ismar.2005.31

[34] Emma van Amersfoorth, Lotte Roefs, Quinta Bonekamp, Laurent Schuermans, and Bastian Pfleging. 2019. Increasing driver awareness through translucency on windshield displays. *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings* (2019). https://doi.org/10.1145/3349263.3351911

[35] VideoGameGeek. 2021. *Video Game Guide to Genres.* https://videogamegeek.com/wiki/page/Video_Game_Guide_to_Genres

[36] G. Stewart Von Itzstein, Mark Billinghurst, Ross T. Smith, and Bruce H. Thomas. 2017. *Augmented Reality Entertainment: Taking Gaming Out of the Box.* Springer International Publishing, Cham, 1–9. https://doi.org/10.1007/978-3-319-08234-9_81-1

[37] WayRay. 2021. *Holographic Augmented Reality Display.* https://wayray.com/

[38] Richard Wetzel, Rod McCall, Anne-Kathrin Braun, and Wolfgang Broll. 2008. Guidelines for designing augmented reality games. *Proceedings of the 2008 Conference on Future Play Research, Play, Share - Future Play '08* (2008). https://doi.org/10.1145/1496984.1497013

[39] Gesa Wiegand, Christian Mai, Kai Holländer, and Heinrich Hussmann. 2019. InCarAR: A Design Space Towards 3D Augmented Reality Applications in Vehicles. *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '19* (2019). https://doi.org/10.1145/3342197.3344539

[40] Julie R. Williamson, Mark McGill, and Khari Outram. 2019. PlaneVR: Social Acceptability of Virtual Reality for Aeroplane Passengers. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3290605.3300310

[41] Zhengxia Zou. 2020. Castle in the Sky: Dynamic Sky Replacement and Harmonization in Videos. arXiv:2010.11800 [cs.CV]