Pedalling into the Future: Towards Enhancing Cycling Experience Using Augmented Reality

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Figure 1: An illustration of two themes: (a) navigation and exploration, where AR glasses provide cyclists with surrounding information; (b) group cycling optimization, where a pair of cyclists share each other's location

ABSTRACT

The heightened emphasis on a healthy and sustainable lifestyle has led to a surge in the popularity of cycling and an increased interest in integrating emerging technologies into the cycling experience. Despite its promising potential and the advancements in leveraging Augmented Reality (AR) for cycling assistance, a significant gap exists in understanding cyclists' perspectives, preferences, and concerns regarding AR technology. This paper aims to address this gap through in-depth interviews with eight cyclists, seeking to uncover potential benefits and challenges across six themes. These themes encompass addressing safety concerns, optimising navigation and training performance, facilitating biomechanical adjustments, and enhancing group cycling dynamics. We anticipate that the initial insights gained from these interviews will guide future researchers and practitioners interested in exploring the intersection of cycling and AR technology.

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CCS CONCEPTS

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

KEYWORDS

Cycling experience, cyclists, cycleHCI, interaction design, augmented reality

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1 INTRODUCTION AND BACKGROUND

Cycling enjoys an increasingly growing popularity thanks to promoting a healthy and sustainable lifestyle in today's society. This rise in interest is further accentuated by the emergence of new technologies, contributing to a noticeable increase in cycling-related research. Augmented Reality (AR) emerges as a key technology transforming the cycling experience, offering novel ways to assist cyclists [10, 14]. For instance, AR applications have been developed to provide real-time visualizations that assist cyclists at intersections [10], and alert them to potential hazards [14]. While pioneering studies showcase the potential of AR in improving cycling experiences, they primarily focus on empirical testing of new systems. This approach may not fully capture cyclists' needs, possibly limiting the optimal utilisation of AR in the cycling context. Although previous research has delved into cyclists' attitudes towards urban commuting experiences [11] and interactions with automated vehicles [1], there remains a notable gap in achieving a comprehensive understanding of cyclists' perspectives, preferences, and concerns with AR technology. Therefore, we argue for the necessity of conducting in-depth research that prioritizes understanding cyclists' viewpoints.

This work investigates how AR technologies, especially head-mounted displays (HMDs), can be employed to augment the cycling experience. Through in-depth interviews with eight cyclists, we take the first step to bridge the existing gap by presenting firsthand perspectives on integrating AR technologies in cycling, uncovering potential benefits and challenges that prior studies might overlook. Understanding how cyclists perceive and interact with AR technology can guide researchers, designers, and developers in creating user-centred AR applications that enhance rather than disrupt the cycling experience. Hence, we believe our exploration will contribute to the future advancements of AR implementations in cycling scenarios.

2 METHODOLOGY

Our goal is to achieve a deep understanding of cyclists and explore the ways in which AR technology can enrich the cycling experience. To accomplish this, we conducted semi-structured interviews and performed a complete data analysis using thematic analysis [3]. This study was approved by the university's Human Ethics Committee.

Participants. We recruited participants via flyers posted on social media or from personal contacts. We sought participants who are recreational or experienced cyclists. Individuals who only knew how to cycle without a deeper involvement in the activity were excluded from this study. In total, eight participants (one female) were recruited. Among them, five cycle daily, three weekly. Geographically, five primarily cycled in Australia, one each hailed from Finland, Spain, and China. In assessing their expertise, participants self-rated on a scale from 1 (non-professional) to 7 (professional), resulting in four ratings of 3 and the remaining four with ratings of 1, 4, 5, and 6, respectively. Notably, five participants self-identified as early adopters of technology. While age was not specifically queried, three participants fall within the 18-24 age category, four are aged 25-34, and one is in the 35-44 age group. This deliberate recruitment with varying levels enables us to gain a more comprehensive understanding of varied perspectives. Details of the demographic results can be found in supplementary documents.

Procedure and Data Analysis. Interviews were conducted individually either in-person or online, began with a consent form outlining recording and quotation usage. We started with a demographic questionnaire, followed by a series of open-ended questions. These questions delved into their cycling experiences, the information or assistance they need during cycling, their understanding of AR technologies, and more. Each interview had a duration of approximately 30-60 minutes. Audio recordings were made with participants' consent for transcription and analysis. The first author conducted the coding process, following an iterative process involving reassessment and merging of codes. Once established, the codes were sorted into thematic categories, and the initial categorization of themes was discussed and reviewed by all authors. NVivo was used as the tool for categorising, coding, and analysing the interview data. As a result, we ended up with six themes, as discussed in the next section.

3 FINDINGS

We highlight six key themes that have emerged from a thorough analysis of the interview data, offering valuable insights into the varied perspectives of cyclists regarding integrating AR into their cycling experiences. The following subsection provides a detailed exploration of these themes. Figure 1 shows an illustration of two themes.

3.1 Theme 1: Road Safety Enhancement

Road safety enhancement emerged as a prominent theme across all interviews, reflecting a collective concern among cyclists for road safety, particularly in urban environments.

"When I first got to Australia, I was unsure about cycling rules, like riding without a bike lane. One day, I was riding on the road without a lane, a car honked and whizzed by, making me uneasy. ... Cyclists need to know the rules, but Google Maps doesn't cover that when you're riding." (P2)

Participants consider AR glasses a valuable tool for providing visual cues related to road conditions and the proximity of other road users, ultimately enhancing safety. In addition, P7 stated *"I have a taillight with the radar that detects the car coming behind, but I don't think it's very useful, because even with the warning, you don't know if it's going to speed up or slow down, and you can't see it"*. They anticipate that AR glasses could provide real-time reminders about road conditions at intersections or offer an intuitive display of rear vehicles. This aligns with prior endeavours, which predominantly revolve around warning systems [10, 14]. While these initiatives open up possibilities for real-time feedback and assistance using AR glasses, their scope is primarily confined to controlled in-lab experiments. Bridging the divide between laboratory-based research and real-world applications is essential to validate the efficacy and usability of AR glasses in diverse cycling environments.

Although conducting experiments in naturalistic (here: outdoor) settings poses inherent challenges, future studies can explore a set of controlled field trials that enable ramp-up from lab experiments to comprehensive in-the-wild studies.

3.2 Theme 2: Navigation and Exploration

Participants consistently voiced concerns about navigational challenges. Two participants (P3, P8) relied on audio navigation but struggled with ambient traffic noise, suggesting a need for clearer (visual) cues. Others (P1, P2, P4, P5, P6, P7) faced challenges with mobile or bike computer navigation, especially at complex intersections. Consequently, participants see AR glasses as a promising tool to improve navigation and enhance exploration.

All participants unanimously highlighted the need for precise indications and route guidance, identifying AR glasses as an effective solution. Meanwhile, participants stressed the significance of personalised route navigation aligned with individual preferences. For instance, P3 noted *"Sometimes when I want to commute, Google Maps directs me to those bike-specific trails, which can be a detour. I'm not really into those routes because sticking to regular roads is faster. Plus, on those trails, there are pedestrians, so you can't really pedal fast, and I worry about accidentally running into someone"*. On the other hand, P5 prioritizes 'fun' in their route choice, as they stated *"When I plan the route, I try to plan a route that is not the shortest or quickest but the most fun one. Usually, a route that is green is more fun than a very urban route."* Accordingly, participants desired AR route recommendations that provide details on road conditions and estimated cycling time. Noting that while the Strava app (a platform for tracking and sharing fitness achievements) offers some of these features, integrating AR could enhance the experience by offering immersive information on-the-go. Furthermore, participants expressed a keen interest in immersive explorations of surrounding information, pointing out *"even if the route is familiar, I might have no idea about the surroundings" (P5)*. These views highlight the preference of offering personalised recommendations and comprehensive environmental information.

While AR navigation has been extensively studied in areas such as automotive and pedestrian navigation, there remains a notable gap in research concerning its application in highly dynamic activities like cycling. Currently, research in this area is in its early stages, primarily consisting of conceptual models [6]. To advance the field, future investigations could thoroughly explore this aspect, possibly incorporating personalized navigation systems to enrich the immersive exploration experience.

3.3 Theme 3: Entertainment and Gamification

Recreational cyclists (P2, P8) expressed a keen interest in incorporating entertainment features into their rides. Drawing inspiration from popular apps like Pokémon Go, they envision an AR cycling experience that blends the joy of exploration such as *"collecting golden coins"*. Additionally, participants also expected to *"browse my Spotify playlists during rides"*, envisioning the potential of using AR glasses to amplify overall enjoyment.

Previous research has primarily concentrated on elevating the indoor cycling experience through Virtual Reality (VR) [2]. Aapplications like Strava also incorporated gamification aspects by assigning virtual awards based on timed segments of routes. However, the potential of using AR HMDs in cycling remains relatively unexplored. Unlike VR, implementing AR gamification in cycling poses unique challenges, with safety considerations taking precedence. Achieving a secure integration of gamification and interaction within AR cycling experiences will need to address safety concerns, such as real-time environment detection and the incorporation of instant hazard alerts. Moreover, effective interaction design requires further exploration, as a crucial aspect of successful gamification implementation. While progress has been made in understanding cycling interaction [7, 9], a thorough examination is required to integrate AR-enhanced gamification elements while prioritizing safety and user experience.

3.4 Theme 4: Personal Training and Exercise Metrics

Participants, particularly those passionate about exercising and improving cycling skills (P1, P3, P4, P5, P6, P7), highlighted the significance of personal training metrics. Currently, they use different devices such as bike computers, smart-watches, heart rate monitors, etc., to record and monitor their training data. While generally satisfied with these devices, there is a collective sentiment that adopting AR glasses could yield benefits, including mitigating the risk associated with looking down and improving the intuitiveness of data presentation. Interestingly, despite recognising the potential utility of data visualisation through AR glasses, none of the interviewed individuals had encountered any recently released commercial products, like [5]. This apparent lack of adoption can be attributed to perceived functional limitations when compared to the currently favoured bike computer, as well as safety concerns. *"I reckon it's a bit more gimmicky than practical at the moment. It's got the same functions as my regular bike computer, so I wouldn't shell out for it unless it comes with super-strong security warnings and some extra features. Of course, the most important thing is that I need to know if it's safe to wear"*, P4 said, even though they self-identified as an early adopter of new technologies. This underscores the need for thoughtful design of data displays on AR glasses. Achieving a balance between delivering valuable information and preventing visual distractions becomes crucial in designing AR systems for cycling. Therefore, future studies should address functional limitations and emphasise safety features.

3.5 Theme 5: Biomechanical Studies and Scientific Cycling

Experienced cyclists (P1, P3, P6, P7) emphasized the importance of riding postures and bike fitting for preventing injuries and enhancing comfort, performance, and efficiency. Biomechanical experts currently utilize force sensors and motion capture to analyze cyclists' joint angles, body positions, and movements. Participants view AR as a valuable tool in this process. "*Currently, they (biomechanical experts) use computers to visualize what is happening and decide how to adjust the bike to fit properly, and I believe that there should be a lot of potential using AR to have more situated information and more real-time information of what is happening with the measure that these biomechanical experts are getting" (P6)*. In this context, AR could provide visual feedback on how adjustments affect body mechanics, offering instant validation. Furthermore, participants also emphasised the importance of receiving reminders to adjust their postures while riding. *"Because, like, when you're on the road, it could be a few hours straight, and holding the same position for a long time might mess you up in places, you know. So, I'm hoping for something that can give you a heads-up" (P7).*

Prior work incorporated visual [13] or auditory [12] feedback for scientific training. However, the use of AR HMDs remains unexplored, holding high potential to transform cycling into a more effective form of exercise, mitigating the risk of improper body postures leading to inefficiencies.

3.6 Theme 6: Group Cycling Optimisation

Group cycling, a popular and valued activity, benefits greatly from optimized dynamics. Participants see AR technology as a key enhancer for group rides, particularly in maintaining awareness of each cyclist's location and providing shared views. *"When we're riding in a group, some folks are faster, some slower. It'd be great if the faster ones could know where the slower ones are in real-time and wait up for them"* (P3). *"When at the back, you often rely on hand signals from the front, but sudden stops or unexpected obstacles are hard to communicate immediately. If the front person brakes suddenly, we might collide. Sharing vision could really help avoid accidents in such situations"* (P4). In addition, participants expressed the prospect of AR offering real-time metrics of leading riders in team competitions, enabling those at the rear to visualise their peers' efforts. *"When you are doing, especially in competition, the people in front are wasting a lot of energy, and the people in the back are saving energy. If people in the back are aware of the capacity of the front, they can make a decision on when to take the front and give them time to rest" (P6).* This holds promise for fostering more strategic and energy-efficient group cycling. While prior research has explored enhancing group collaboration in cycling through helmets [15], the use of AR remains relatively under-explored. This presents an exciting area for potential exploration in future studies.

3.7 Design Insights

Overall, participants anticipate AR technology holds promise for revolutionizing the riding experience, offering advancements in safety, navigation, training, biomechanical analysis, and group dynamics. However, challenges have been identified, particularly concerning the practicality of AR glasses, and the potential distraction caused by the virtual information. Derived from the insights acquired, we present recommendations and provide guidance on the design of forthcoming developments.

Robust Design. Participants emphasised the importance of design for AR glasses, focusing on aspects such as comfort, lens selection, weight, and more. Concerns about the durability of AR glasses, particularly their susceptibility to damage and potential data loss after a fall, were highlighted. Additionally, nearsighted participants raised issues related to the degree of correction of AR lenses.

Attention and Cognition. Safety concerns of wearing AR glasses appear through all the themes, which surfaced as a crucial factor. Determining whether AR glasses are intended to "enhance security" or inadvertently "trigger security incidents" requires a nuanced understanding of human perception, especially attention and cognition. Previous investigation of AR and its impact on human attention has predominantly focused on indoor or automotive environments [4], however, there is a need to investigate how AR interfaces affect attentional resources and cognitive processes in dynamic, real-world cycling environments.

Multi-modal Integration and Interaction. Participants emphasised the necessity of directing a significant portion of visual attention to the road while cycling. Given that AR primarily conveys information visually, there was a demand for supplementary feedback, including auditory and haptic elements, to complement visual cues. This aligns with previous attempts [8] and highlights the need to further investigate AR interaction methodologies [7, 9].

Personalisation, Intelligence, and Credibility. Participants expressed a desire for user-defined information display options, primarily when focusing solely on the cycling experience without being inundated with data. The development of artificial intelligence technology raises hopes for equipment that understands individual preferences, emphasising the need for intelligence in system design. However, participants indicated a cautious reliance on smart devices to avoid excessive trust in danger warnings. This underscores the necessity to enhance the accuracy of system design while considering cyclists' acceptance and trust in support systems, in line with previous findings [10, 14].

4 LIMITATION AND CONCLUSION

While we aim to include a diverse range of participants across backgrounds and expertise levels, our current sample size is relatively small and predominantly consists of Australian participants. We also acknowledge limitations in age and gender representation. Due to the constraints of our small sample size, we were unable to conduct an in-depth analysis of distinctions between different types of cycling, such as competitive versus recreational, nor did we delve into participants' prior exposure to AR technology. Consequently, these factors may impact the interpretation of our findings. Therefore, future investigations should prioritize obtaining a more extensive and diverse dataset, encompassing participants from diverse geographical locations, age ranges, and gender identities. Additionally, deeper exploration into various aspects such as different types of cycling should be undertaken to uncover potentially valuable insights.

Furthermore, while our paper presents themes derived from interview results, we did not fully develop and evaluate AR prototypes tailored for specific cycling scenarios. Subsequent studies could concentrate on prototype evaluation, utilizing quantitative methods such as surveys to gather more extensive data.

Given the evolving landscape of technology, comprehending cyclist preferences and expectations becomes imperative for the integration of AR solutions in the cycling community. Therefore, our work contributes by identifying research themes and design insights aimed at guiding the exploration of AR applications to enhance the cycling experience.

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