Exploring the Design of Augmented Reality for Fostering Flow in Running: A Design Science Study

Research Paper

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Abstract. Flow is an optimal state for athletes, such as runners, enabling peak performance. To achieve flow, three preconditions must be met: clear goals, challenge-skills balance, and unambiguous feedback. Augmented Reality (AR) sport glasses have the potential to foster flow by supporting these preconditions, yet designing effective AR interfaces for endurance running remains challenging due to the difficulty of (re)entering flow and the dynamic outdoor environment. In a Design Science Research (DSR) study, we explored how AR interfaces should be designed to foster flow in running through two iterative design cycles. We develop and evaluate an AR artifact, gathering insights from nine user interviews conducted after field testing in both cycles. Based on these findings, we derive four design recommendations to enhance flow in endurance running through AR interfaces. With this, the study contributes design knowledge of AR-supported flow experiences in outdoor sports and offers novel practical guidance for designers.

Keywords: Flow, AR, Sports, Endurance Running, Design Recommendations

1 Introduction

In 2010, Chris Solinsky made sports history by becoming the first non-African athlete to run 10 km in under 27 minutes. Reflecting on his performance, Solinsky described himself as being in a state of flow, which enabled him to push beyond his limits and surpass expectations (Csikszentmihalyi et al., 2018). According to the flow theory, flow is defined as “the state in which people are so involved in an activity that nothing else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it” (Csikzentmihalyi, 1990, p. 4). In this state, athletes can reach optimum performance, where body and mind unite, time seems to disappear, and fatigue fades despite peak physical exertion (Csikszentmihalyi et al., 2018; Csikzentmihalyi, 1990; Swann et al., 2012). However, in endurance running, achieving and maintaining flow is highly individualized, influenced by factors such as training experience, physical conditioning, mindset, and goal setting (Antonini Philippe et al., 2022; Jackson, 1996). Once interrupted by a misstep, a distraction, or negative thoughts, flow can be difficult to (re)enter, disrupting the rhythm and performance of a run (Antonini Philippe et al., 2022; Schüler & Brunner, 2009; Swann et al., 2012). Traditional strategies such as mindfulness and mental visualization are recommended for enhancing flow, yet these techniques can require months or even years of practice (Csikzentmihalyi, 1990). Endurance running of long-distance runners, commonly understood as 5 km and beyond (Blagrove et al., 2018), relies on accessing internal and external feedback over time to adjust to optimum performance and facilitate flow (Csikszentmihalyi et al., 2018; Swann et al., 2012). Internal feedback includes physiological cues like breathing patterns, heart rate, and muscle fatigue, while external feedback comes from environmental factors. Unlike in team sports, where athletes can draw on constant external input from team members, coaches, and opponents, individual runners have limited access to external cues, requiring runners to rely largely on self-monitoring (Antonini Philippe et al., 2022; Csikszentmihalyi et al., 2018; Jackson, 1996).

Augmented Reality (AR) glasses offer a way to provide external real-time feedback for individual runners. Lightweight models from brands like Everysight (2025), ENGO (2025), Activelook (2025), and start-ups like QIDI (2024) are specifically designed for the sports context. They resemble the design of familiar sports eyewear and can provide a comfortable AR experience in sports. Unlike smartphones or smartwatches, which are stored in a pocket or worn on the wrist, and require active movement to access information, AR glasses can project data directly into the runner’s field of view. This hands-free interaction can help monitor physical condition, support goal pursuit, enhance motivation, and facilitate entering a flow state (Barhorst et al., 2021).

However, AR interfaces in endurance running merge two distinct realities: the dynamic physical world, which constantly changes due to the runner's movement and unpredictable outdoor conditions, and the digital overlay, which relies on screen-based visualization to deliver real-time feedback (Barhorst et al., 2021). This circumstance presents unique visual and usability challenges for user interface (UI) design. For instance, high glare, shifting light conditions, and environmental distractions can impact both AR display readability and the runner’s attentional focus (Dünser et al., 2012).

Emerging research explores how AR influences flow states, the moderators shaping AR flow experiences, and the outcomes of AR-induced flow. Studies across various domains, including in education (Arifitama & Rahman, 2024; Giasiranis & Sofos, 2017; Lu et al., 2024; Salar et al., 2020; Wang et al., 2023), educational games (Bressler & Bodzin, 2013; Lee & Chai, 2017), tourism (Lin et al., 2019) and consumer experience (Arghashi & Yuksel, 2022; Barhorst et al., 2021; Serravalle et al., 2023; Yuan et al., 2021) have investigated the impact of factors, such as usefulness and novelty, on experiencing flow. However, these studies have focused on relatively static contexts with minimal body movement, using standard AR glasses not suited for the dynamic nature of outdoor sports. This limits their transferability to endurance running and leaves a critical gap in understanding how to design interfaces that support flow in such settings. To address this, we investigate the research question: *How should the UI of AR glasses be designed to foster flow in endurance running?*

We address this question using a Design Science Research (DSR) approach (Hevner, 2007), focusing on the iterative design and evaluation of an innovative AR interface across two design cycles. This paper highlights the evaluation phase, drawing on insights from nine user interviews conducted after field testing the artifact in both cycles. From the collected data, we identified nine user stories that capture runners' desires and expectations, and extracted four design recommendations for promoting flow in endurance running through AR interfaces. In doing so, we contribute to the design knowledge of AR-supported flow experiences in outdoor sports and provide practical guidance for UI designers in this domain.

2 Theoretical Background

2.1 Flow in Sports

Flow experience is characterized by six key dimensions: focused attention, merging of action and awareness, sense of control, loss of self-consciousness, altered sense of time, and autotelic experience (Csikzentmihalyi, 1990; Swann et al., 2012). When these align, athletes may reach a state of optimal performance and a harmonious balance between body and mind – surpassing the so-called "runner's high". To achieve this in endurance running, three preconditions must be met (Csikszentmihalyi et al., 2018):

1. *Clear goals*. The runner must have a specific, tangible objective, such as reaching a target distance or pace. A well-defined goal provides direction and purpose, helping the runner push their physical and mental limits.
2. *Challenge-skills balance*. The perceived level of challenge should match the runner's abilities, ensuring they neither feel physically underwhelmed nor overwhelmed, but rather perform at an optimal level.
3. *Unambiguous feedback*. Continuous internal and external feedback is necessary for the athlete to assess their performance, make real-time adjustments, and maintain motivation during the endurance run.

Among these preconditions, unambiguous feedback is where AR glasses could provide a unique advantage. During an endurance run, athletes continuously collect internal and external cues, using them to make performance adjustments. This process requires a high level of attentional control, runners must learn to interpret and respond to signals from both their body and the surrounding environment quickly and accurately (Antonini Philippe et al., 2022; Swann et al., 2012). However, feedback is not only about physical performance optimization but also about psychological reinforcement. Every positive feedback instance, whether internal (e.g., feeling strong and controlled over the run) or external (e.g., reaching a target pace), reinforces the runner's belief in their abilities and increases their confidence in achieving their goal (Csikszentmihalyi et al., 2018). This mental reinforcement is particularly relevant in outdoor environments, where unpredictable elements such as weather, terrain, or traffic cannot be controlled, but one's own mindset and reaction to these challenges can be managed (Chavez, 2008). AR sport glasses can reinforce a runner's goals by projecting real-time target paces or distance markers directly into the field of view, keeping objectives constantly visible rather than relying on mental recall. Maintaining this focus is vital for entering flow, as it minimizes negative thoughts, such as overanalyzing performance or negative self-talk, which could disrupt the immersion of the run (Sugiyama & Inomata, 2005; Swann et al., 2012). AR sport glasses can also maintain challenge-skills balance by comparing real-time metrics to personal benchmarks, indicating whether the effort is too easy or too demanding (Brannon Barhorst et al., 2021; Jackson, 1996).

From a neuroscientific perspective, achieving flow during an endurance run is associated with a temporary downregulation of prefrontal cortex activity, as described by the transient hypofrontality hypothesis (Dietrich & Audiffren, 2011). This neurobiological adaptation occurs in response to prolonged physical exertion, allowing the brain to conserve energy by reducing activity in cognitive control regions while prioritizing sensorimotor efficiency. In this state, motor functions become highly automated, with the motor cortex executing well-rehearsed movement patterns of the endurance run (e.g., stride regulation, posture maintenance, and heart rate control) with minimal conscious interference (Dietrich & Audiffren, 2011; Dietrich & Stoll, 2010). As a result, the athlete is fully absorbed by the run, allowing the “performance to feel effortless and automatic” (Chavez, 2008, p. 75). Furthermore, cognitive processing shifts away from detailed analytical thinking, and the athlete becomes fully immersed in the rhythmic nature of the endurance run (Csikszentmihalyi et al., 2018).

Flow is a deeply personal experience, varying in intensity and sequence across individuals (Swann et al., 2012). Research suggests that the more frequently an individual experiences flow, for example during an endurance run, the greater their ability to recall and re-enter the state in future runs (Antonini Philippe et al., 2022; Schüler & Brunner, 2009). However, flow is not an easily controlled state, it cannot be accessed on demand. Instead, flow is a result of long-term dedication and refinement of skill. As Csikszentmihalyi emphasizes: "Flow is not a shortcut; it is both the result and the reward of long-term commitment to mastering an activity" (Csikszentmihalyi et al., 2018, p. 159).

2.2 AR Applications and Flow

Prior research has identified several factors that positively influence the AR flow experience, such as perceived usefulness (Arghashi & Yuksel, 2022), naturalness (Lee & Chai, 2017), informativeness and novelty (Yuan et al., 2021). Arifitama and Rahman (2024) reported generally positive technology acceptance of flow-inducing AR applications among students at a university, but they also raised concerns about feasibility and the actual benefits in a classroom setting. Related work has shown that AR instructions positively influence the flow experience and motivation in scientific learning (Wang et al., 2023). However, it remains unclear whether these findings translate to the physically demanding context of outdoor sports, which also raises design questions for flow AR experiences in running. In particular, lightweight AR sport glasses must maintain a balance in the amount of information they present, too little data may be ineffective, while too much can overwhelm the user and disrupt flow (Havlucu et al., 2021). Nevertheless, not just the quantity but also the content type and the user’s perceived control over it are critical to sustain usability and to improve the AR flow experience, as Javornik et al. (2019) demonstrate in outdoor settings. Furthermore, motion sickness and discomfort present further design challenges for AR applications, particularly with dynamic elements (Kaufeld et al., 2022). Highlighting the complexity, Barhorst et al.

(2021) emphasized the role of interactivity, vividness, and novelty influencing flow and shaping AR experiences. Novelty is particularly important in driving user engagement and flow, as supported by the model of human motivation after the Yerkes-Dodson law (Yerkes & Dodson, 1908), "without an appropriate level of external stimulation, we become disengaged and bored" (Csikszentmihalyi et al., 2018, p. 28), reinforcing the idea that AR must introduce engaging yet well-calibrated stimuli to sustain flow states.

3 Designing AR Interfaces to Foster Flow in Running

This research project follows the DSR methodology, guided by Hevner's (2007) three-cycle framework: Rigor, Design, and Relevance. To explore how AR interfaces should be designed to foster flow in running, we ground our design in flow theory and iteratively evaluate the resulting artifact in real-world field tests. By integrating theoretical foundations with practical applicability through iterative design and evaluation, we ensure a balanced and scientifically grounded approach (Hevner, 2007).

3.1 Design Process

We conducted our DSR project in two iterative design cycles, as summarized in Figure 1. In the *first cycle*, we began by conducting an exploratory literature review to gain insights into flow theory and existing research on fostering flow through AR interfaces, as detailed in the theoretical background. This helped us identify key concepts informing the initial design of the artifact, such as displaying minimal content and using heart rate data as a performance feedback metric.

Next, we selected and tested the Everysight AR glasses, which are state of the art lightweight AR glasses developed specifically for the outdoor sports context (Everysight, 2025), and consulted with industry experts to refine our understanding of both their potential and their limitations. The selected AR glasses contain a single-eye display in the upper left corner of the right lens, as depicted in Figure 2. The glasses can be connected to smartphones and smartwatches to display information on their AR display, such as real-time heart rate data. The glasses include a physical button on the frame that can be used for simple inputs. Afterwards, we designed an initial AR interface aimed at fostering flow for runners. We then developed a functional prototype for the Everysight AR glasses. To evaluate its usability and helpfulness for fostering flow, we conducted qualitative user testing, where four runners used the prototype while running, followed by in-depth interviews. Based on their feedback, we critically reflected on our initial design and identified areas for improvement, initiating the second cycle.

We started the *second design cycle* by analyzing the shortcomings of our initial design. Based on these insights, we refined our conceptualization of the artifact. We then adapted the prototype implementation accordingly and conducted another round of qualitative evaluation, following the same approach as in the first design cycle. Finally, we used user stories to reflect on all evaluation results, synthesizing our findings to create a final AR interface design for runners and derive design recommendations.

In this paper, we present the findings of our research, with a particular focus on artifact design and evaluation. Specifically, we first introduce the prototype developed in the initial design cycle and examine its adaptations and refinements in the subsequent cycle. We then provide an in-depth analysis of user interviews conducted after each design cycle's user testing phase, extracting practical design recommendations for AR interfaces aimed at enhancing flow experiences for endurance runners.

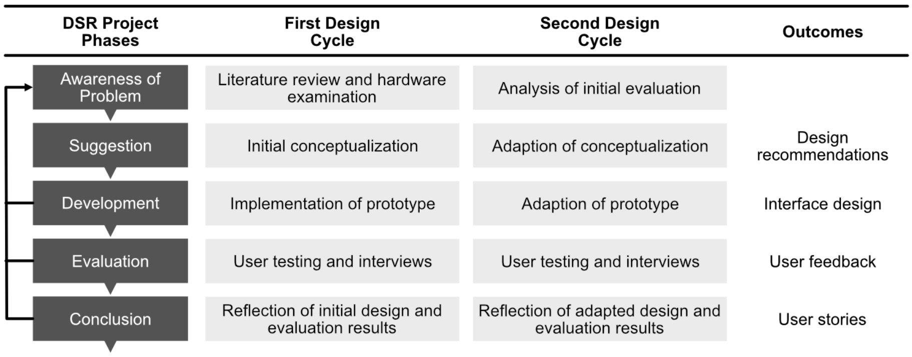

Figure 1. Overview of our DSR approach.

3.2 Artifact Designs

In the *first design cycle*, we implemented an AR interface displaying the heart rate as a numeric value in the center of the available display, as shown in Figure 2. We chose to present the heart rate, a commonly used metric in endurance training, providing a direct and quantifiable measure of effort, allowing athletes to regulate intensity while optimizing performance and recovery (Seiler, 2010; Stöggl & Sperlich, 2015). Heart rate has been proposed as a potential flow indicator, as fluctuations in autonomic nervous system activity reflect changes in engagement and challenge levels (Tozman et al., 2015), thus providing the athlete with consistent and non-intrusive external feedback on physical performance to support flow induction (Csikszentmihalyi et al., 2018). To display real-time heart rate data, we used a smartwatch to measure the data and connected it to the AR glasses using a dedicated smartphone app to transmit data between devices. The first prototype was evaluated, with participants criticizing the numerical display as unengaging and cognitively demanding to interpret.

In the *second design cycle*, based on feedback from the first evaluation, we introduced a dynamic visual element to enhance novelty (Javornik et al., 2019) and implement non-numeric feedback, reducing cognitive workload (Havlucu et al., 2021; Javornik et al., 2019), presenting the second interface design visualized in Figure 2. This design includes a rotating circular element with two gaps, allowing runners to develop a better sense of control and feedback on their physiological state. At low heart rates, the rotating element is displayed compactly around the numeric value. As the runner approaches a target heart rate associated with a potential flow state, individually defined based on personal experience, the element gradually expands and fades to minimize cognitive distraction and visually reflects the transition into flow, aligned with the transient hypofrontality hypothesis (Dietrich & Stoll, 2010). Additionally, a red frame appears when the heart rate reaches an individually defined critically high zone, acting as an injury prevention cue by signaling intensity beyond a healthy endurance range (Csikszentmihalyi et al., 2018; Esteve-Lanao et al., 2007). To maintain user autonomy and prevent cognitive overload, runners can manually activate or deactivate the display using the physical button on the frame of the AR glasses. This feature grants control over the system, allowing users to exit the interface if it distracts or induces motion sickness (Javornik et al., 2019; Kaufeld et al., 2022).

After conducting another round of evaluation in the second design cycle, we again refined the design. For instance, we removed the numerical heart rate data while keeping the non-numerical visual elements to further reduce the cognitive load (Havlucu et al., 2021; Javornik et al., 2019). This results in the final design visualized in Figure 2.

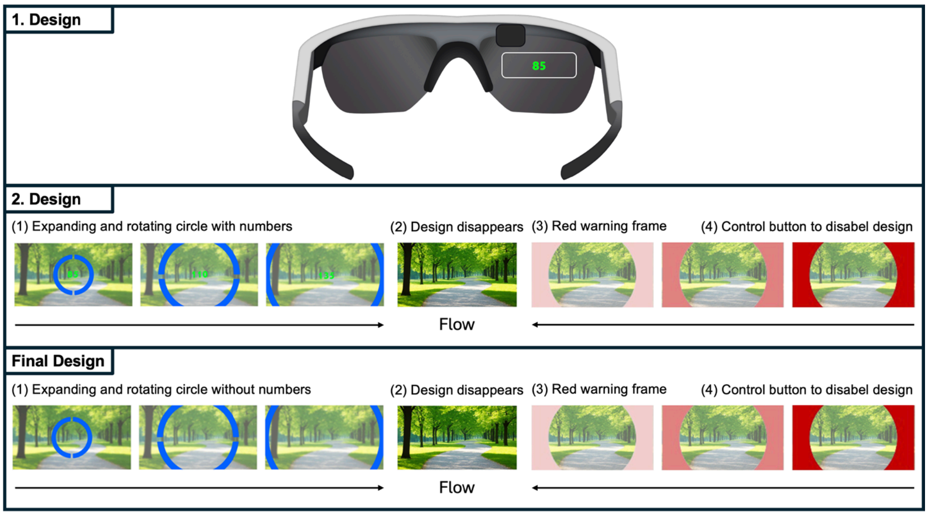

Figure 2. Design and development of the artifact within the two design cycles.

Table 1. Overview of participants

ID	Cycle	Age	Gender	Motivation for running	km/week	km in test	Weather
P1	1	27	Female	Overall fitness	40-50	14	sunny
P2	1	27	Male	Overall fitness	6-12	14	sunny
P3	1	25	Female	Competition, overall fitness	21-24	14	cloudy
P4	1	25	Male	Overall fitness	14-24	14	sunny
P5	2	25	Female	Skill development	7-10	8	cloudy
P6	2	28	Male	Competition	20-25	7	sunny
P7	2	28	Female	Endurance	20-21	5	cloudy
P8	2	27	Male	Competition	40-50	11	sunny
P9	2	30	Female	Skill development	13	10	sunny

4 Evaluation

4.1 Participants

We recruited nine participants for the evaluation, four in the first design cycle and five in the second design cycle. We recruited participants through personal networks and local running clubs to ensure we included ambitious runners who ran regularly. Participation was voluntary and not compensated. No one had prior experience with AR glasses in a sports context. Table 1 provides an overview of the participants.

4.2 Procedure

In both design cycles, we qualitatively evaluated the AR interface through field tests, followed by in-depth interviews. Before each user test, we explained the design, ensured participants understood the interaction with the system, clarified any remaining questions, and checked technical functionality. To maintain authentic running conditions, participants followed their usual training routes. A researcher cycled behind the runner (10-20 meters apart), remaining out of sight to observe without interfering and only intervening in case of technical problems. In one case, the smartphone transmitting heart rate data stopped working, resulting in a temporary service interruption. The incident was noted, but the participant was not excluded, as the experience provided valuable insights. After the run, we removed the technical setup and conducted semi-structured interviews based on Döring & Bortz (2016). The interviews lasted on average half an hour and included questions on personal background, the artifact's usability, and its potential for fostering flow. Example questions included: "How intuitive did you find the interface?", "Did the system help you feel a balance between the challenge and your abilities?", and "Based on the visual feedback you received, did you know what to do?" Following Braun and Clark (2006), the interviews were recorded, transcribed, and analyzed using a combined deductive-inductive approach. Flow-related codes were defined deductively, based on flow preconditions from flow theory, while usability-related themes emerged inductively from the data to capture unexpected user insights. Based on the identified themes, we derived user stories, which provide a medium to express expected or desired functionality in semi-structured natural language from the user's perspective (Savolainen et al., 2010).

4.3 Results

Based on feedback from the interviews, we identified three themes related to flow preconditions and usability, respectively. From these, we derived nine user stories that capture the users' desires and expectations for AR interfaces to foster flow in running.

Flow

Clear Goals. All participants agreed that having a performance metric constantly displayed in the field of view helped them stay focused on achieving their running goals.

One participant highlighted: "Now you have a gadget that you can use without constantly being pulled out of your routine and movement pattern, and you're still reminded not to run too fast" (P6). This also shows the advantage compared to commonly used wearables such as smartwatches: "having it basically in the field of view without having to look away, that's a nice improvement" (P8). Based on this insight, we derive the following user story: US1: *"As a user, I want to see goal-relevant indicators in my field of view so that I can stay focused on achieving my performance goal."* While participants had different personal exercise goals, they all emphasized the importance of monitoring metrics relevant to their progress. Pace was often preferred, whereas our prototype visualized heart rate without customization options. To address this need, we formulate the following user story: US2: *"As a user, I want to select the specific indicator that aligns with my training goals so that I can track and improve my performance*."

Challenge-Skills Balance. The continuous feedback provided through the AR display enables users to assess their current performance in real-time, helping them maintain a challenge-skills balance. As a participant noted: "because it shows in real-time whether you are in the right zone or not" (P1). This real-time feedback allowed runners to adjust their pace as necessary to remain within an optimal range, thereby supporting their flow: "I can really feel inside, when I'm running in the green zone, it gives me such a boost" (P5). Additionally, the use of color-coded indicators made it easier for users to interpret their performance and identify the optimal zone effortlessly. Therefore, we derive US3: *"As a user, I want real-time, intuitive feedback on my performance so that I can maintain an optimal challenge-skills balance to stay in or enter my flow state."*

Unambiguous Feedback. The AR display continuously provided performance metrics, positioned in the corner of the glasses. This allowed users to either focus on the feedback or ignore it as needed: "I could focus on running without having the feedback from the glasses. But then I could also make a conscious effort to look at it and then get that information" (P2). Additionally, users had the option to completely switch off the display using a physical button on the frame, giving them full control over when to access the feedback. We synthesize this in US4: *"As a user, I want to decide when I view performance feedback so that I can stay focused on my run."* However, particularly in the first design cycle, some users found it difficult to interpret the presented performance data: "So what does the number mean now? Is it good, bad, or what can I do differently?" (P1). To address this, the second design cycle introduced additional visual elements alongside numerical data, improving interpretability. In particular, users found the heart rate warning system helpful in recognizing when their heart rate was too high. Therefore, we derive US5: *"As a user, I want easily interpretable feedback so that I can make necessary behavior adjustments without cognitive overload."*

Usability

Distraction. The AR display was perceived as less distracting than other commonly used devices, such as smartwatches, since users did not have to move their wrist or look down to check their performance metrics. Instead, having the information directly in their field of vision was seen as a significant advantage: "I think the advantage is that you don't have to look anywhere else and that you have the information right in your field of vision" (P1). This allowed users to stay more focused on their run compared to checking a smartwatch and resulted in the following user story US6: *"As a user, I want* *performance indicators displayed in my field of vision so that I can stay focused on my run."* However, some participants reported that viewing the heart rate metric could momentarily disrupt their flow: "I would get ripped out of [my flow] as soon as I looked at my heart rate" (P2). This issue was often temporary and resolved after users became accustomed to the AR interface: "In the end it was fine. I think it was just getting used to running with the glasses" (P4). Nevertheless, these insights highlight the need for an unobtrusive and intuitive AR interface design that minimizes distractions and facilitates a smooth adaptation process. US7: *"As a user, I want relevant information to blend seamlessly with the context of running through embodied interaction so that I can quickly adapt to it without disrupting my flow."*

Novelty. While the AR glasses initially felt novel and engaging, participants quickly adapted to them: "you'll eventually stop noticing it" (P1). Despite this familiarity, the interface design, especially in the second design cycle, which featured more intuitive visualizations, remained interesting. Participants appreciated the improvements in interpretability. However, suggestions for a more gamified design sparked mixed reactions. While gamification could enhance engagement, participants expressed concerns that it might create pressure and shift the focus away from the run, potentially disrupting their flow. Therefore, we derive US8: *"As a user, I want an engaging yet subtle AR interface so that it remains interesting without distracting me from my run."*

Readability. Although the AR glasses were specifically designed for outdoor sports, some users found the display difficult to read, particularly in bright sunlight. P9 described the challenge: "The sun started to come out and it was really hard to actually see it. I could see it the best when I went through the tunnels or when I looked down on the pavement". This issue was especially noticeable in certain heart rate zones. While participants could clearly identify their heart rate stage, reading the exact number was sometimes difficult: "I could read it very well when I was running in the green area. In the blue circle, the number was a bit small, and I couldn't read the red at all" (P5). While the color-coded feedback effectively communicated whether their heart rate was in an optimal or critical range, the numerical values were not always easy to recognize. This leads to US9: *"As a user, I want all visual elements to be easily readable in different lighting conditions so that I can effortlessly track my performance."*

5 Discussion

This study explored how AR interfaces can be designed to foster flow in endurance running. Through two iterative design cycles, we developed and evaluated an AR artifact, identifying key factors influencing flow preconditions and usability.

Our findings suggest that lightweight AR glasses can be used to enable embodied human-technology interaction during endurance runs, offering a suitable interface for unambiguous, continuous yet non-intrusive performance feedback, relevant for promoting flow. In individual endurance running, feedback cues from competitors, coaches, and team dynamics are absent (Antonini Philippe et al., 2022; Csikszentmihalyi et al., 2018). AR can fill this gap by providing *unambiguous external feedback*, such as heart rate visuals, that help runners monitor their efforts. Second, the interface can reinforce *clear goals* by visualizing heart rate zones in alignment with the optimal flow zone. Third, AR feedback supports the *challenge-skills balance* by helping runners regulate their intensity in real time, allowing them to stay within their optimal performance zone. The study thus confirms the importance of clear goals, challenge-skills balance, and unambiguous feedback for enabling flow in AR-supported running. Moreover, our design exploration offers a tangible and first evaluated blueprint for how AR technology can be utilized for fostering flow in running.

Further, we identified new insights into the usability and adaptability of AR interfaces in outdoor sports, highlighting specific design aspects that require particular attention to support flow during running. Novelty was identified as an influencing factor in the AR experience, confirming previous findings by Javornik (2019) while extending its relevance to the flow context. Our findings suggest that novel dynamic UI elements, such as spinning circles, can provide stimuli that support sustained engagement and positively influence the experience. This aligns with the response model of human motivation, which links optimal stimulation to sustained attention (Csikszentmihalyi et al., 2018; Yerkes & Dodson, 1908), highlighting the need to balance novelty to enhance engagement without causing cognitive overload.

5.1 Design Recommendations for AR Interfaces Fostering Flow in Running

Based on user story insights derived from interview data, we propose four design recommendations to guide research and practice in designing and developing AR interfaces that foster flow in endurance running.

Provide Easily Interpretable Feedback Beyond Numbers to Guide Users (US3, US5, US7, US8, US9). Consistent with flow theory (Csikszentmihalyi et al., 2018; Csikzentmihalyi, 1990), our interviews emphasize the role of the UI design in providing a clear goal, unambiguous feedback, and maintaining challenge-skills balance. As athletes continuously process internal and external cues over the running period, feedback mechanisms should facilitate optimal performance adjustments with minimal cognitive load (Csikszentmihalyi et al., 2018; Havlucu et al., 2021). Our findings suggest that non-numeric visual cues, such as a red warning for high heart rate or a contracting circle for low effort, can effectively guide runners without overwhelming them.

Ensure an Adaptive AR Interface for Seamless, Embodied Interaction (US1, US4, US6, US7). Since re-entering flow after disruption is challenging, the UI design must minimize distractions to keep athletes fully absorbed in the activity (Csikszentmihalyi et al., 2018; Csikzentmihalyi, 1990). Our findings indicate that UI positioning and environmental factors, such as lighting conditions affecting feedback visibility, can disrupt the runner's focus and hinder flow. Moreover, user feedback revealed differences based on experience level. Experienced runners rely more on internal cues (e.g., breathing, muscle fatigue) and prefer minimal visual feedback, whereas novice runners valued continuous AR guidance. To support diverse needs, the AR interface should offer adaptive positioning and visibility to support unobtrusive interaction and sustain flow, aligning with the principles of embodied interaction (Dourish, 2001).

Allow Users to Customize the Performance Feedback Displayed Based on Their Goals (US2). Achieving flow in endurance running requires clear, personal goals

(Csikszentmihalyi et al., 2018). However, these goals can vary significantly among individual athletes, affecting their motivation and preferred feedback metrics (Ong, 2019). Our findings reveal that users want to customize the feedback displayed in AR, e.g. monitoring pace instead of heart rate. This flexibility ensures that different users are supported in their exercise goals, and thus, flow.

Provide a Curiosity-Inducing Design to Maintain User Interest and Engagement (US8). A key challenge in AR interfaces is maintaining engagement without causing distraction or cognitive overload (Havlucu et al., 2021; Javornik et al., 2019). A static numeric heart rate felt monotonous over time, while complex visualizations risked information overload and negatively impacted flow. A dynamic, non-numeric visualization, such as rotating elements for heart rate, balanced engagement and usability by reducing text and presenting visually appealing, intuitive feedback. Thus, refining subtle but novel UI elements can sustain interest without overwhelming runners.

5.2 Limitations and Future Work

Although this study provides valuable insights into the design of AR interfaces for fostering flow in outdoor sports, it has limitations. Our user tests focused solely on endurance runners. While the designs and recommendations identified may also apply to other endurance athletes, such as cyclists or hikers, further research should explore how sport-specific demands shape the requirements to ensure broader applicability. Additionally, while our design was grounded in flow theory and user feedback, we did not directly measure flow induction. Future research should systematically evaluate the effectiveness of the design in eliciting flow experiences, using physiological indicators to detect flow (Schlagowski et al., 2024) or validated flow questionnaires, such as the FKS Flow Scale (Rheinberg et al., 2003). While participants quickly acclimated to the AR interface, our study only covered a single running session. Still, early signs of adaptation during the initial phase, as elaborated by participant P4, suggest that prolonged use could further shape interaction patterns. Future research should explore how familiarity and repeated use influence engagement, preferences, and the role of AR in supporting flow over time. Furthermore, our data aligns with prior research (Ong, 2019), showing that athletes have diverse motivations and prefer different performance metrics. While some participants prioritize pace or distance, others want to focus on heart rate or just enjoy the run. Given our limited sample, we cannot yet determine whether specific motivational profiles predict preferred feedback. Future research should explore how running motivations influence feedback needs to inform more effective AR interface designs.

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