# Sustaining Motivation and Re-engagement Through Accessibility: A Multi-Phase Study of Deaf and Hard of Hearing Players in Mixed Reality Exergames

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Recent trends in mixed reality (MR) exergames offer new opportunities for home-based, visually driven physical activity, but require accessible designs. For example, many conventional fitness systems often depend on spoken instruction and audio cues, limiting accessibility for Deaf and Hard of Hearing (DHH) people. Accessibility and user experience for DHH users are often treated as static, assessed at a single point in time. This framing overlooks how accessibility features may shape their experience, effort, and motivation differently as familiarity develops. Our research, therefore, investigates how DHH users' motivation and engagement evolve in MR exergames across multiple sessions and how accessibility needs shift with familiarity. We conducted a three-phase exploratory study comprising a 10-day in-home user study utilizing *ARWell PRO*, design workshops, and feedback on visual mockup sessions. Our findings show that early-use features (e.g., captions and detailed visual guidance) can become effortful over time due to visual load, while efficiency-oriented features may inadequately support newcomers. Repeated engagement revealed trade-offs between guidance, autonomy, and cognitive effort, positioning accessibility as an evolving rather than static property. We further propose design directions and open research questions around adaptive instruction, modality choice, visual expressiveness, customization effort, and clarity versus discovery.

CCS Concepts: • **Human-centered computing → Empirical studies in accessibility**; **Mixed Reality**.

Additional Key Words and Phrases: Mixed Reality, MR, Exergames, Deaf and Hard of Hearing, DHH

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## 1 Introduction

Physical activity is fundamental to health and well-being, yet Deaf and Hard of Hearing (DHH) people—approximately 5% of the global population [117]—face persistent barriers to accessible exercise [39, 62]. Studies show lower rates of regular physical activity among DHH populations compared to hearing peers due to communication barriers, limited access to interpreted classes, and exercise equipment that relies on audio feedback [10, 61, 119]. These barriers contribute to health disparities that reach beyond fitness, affecting cardiovascular health, social connection, and quality of life [3, 11]. Importantly, addressing these disparities requires sustained engagement over weeks or months [1, 30], as many physical health benefits emerge only through regular activity.

Positively, exergames—digital games designed to promote physical activity—offer a promising avenue to address these inequities. Through home-based, self-directed exercise experiences, exergames can reduce barriers DHH users face in traditional fitness settings [59, 79, 95]. For example, they can lessen dependence on spoken, in-the-moment instruction and lower the coordination burden of communicating with instructors or group members, while giving users greater control over pacing, repetition, and modality of guidance. More recently, mixed reality (MR) exergames have emerged as a distinct class of systems that integrate physical movement with situated digital elements, offering new opportunities for supporting accessible, context-aware exercise experiences [13, 38]. Unlike conventional exercise technologies that rely heavily on spoken instruction or audio cues, MR systems can communicate through visual, spatial, and haptic feedback—modalities DHH users often prioritize [70]. However, realizing this potential requires moving beyond simply identifying accessible features to understanding how these features shape DHH users' experiences and motivation over repeated use.

Despite its importance, sustained engagement remains a critical but under-explored challenge in accessible MR exergaming. Although sustained engagement is necessary for exergames to support physical fitness, the ways users interact with these systems shift as familiarity and expertise increase [74, 85, 90]. For DHH players, this temporal dimension is especially important because orientation-support features, such as captions and persistent visual guidance, are often always-on or manually controlled. As users become familiar with them, these features can shift from enabling access to becoming cognitively burdensome. Conversely, features optimized for experienced players may reduce interaction effort over time [34, 43]. However, they may limit initial access for new DHH players by offering insufficient guidance during early use. This creates a design tension between providing sufficient guidance for learning and allowing space for autonomous, flow-inducing play [2, 44]. Extant extended reality (XR) accessibility research has documented how DHH users interact with immersive systems [21, 47, 70, 118]. However, very few studies have examined how accessibility needs and motivational factors shift across repeated sessions—the temporal context where many accessibility features reveal their limitations or affordances [73, 116].

This temporal dimension aligns with prior findings showing that novelty-driven motivation often plateaus as familiarity increases [74, 87], while sustained participation depends on habit formation and reduced interaction friction over time [22, 77]. For DHH users, accessibility features further shape these dynamics. Supports that aid early learning can become burdens as competence develops, revealing design tensions that single-session evaluations often miss.

Building on a growing body of work, we present a three-phase exploratory study investigating how DHH people experience motivation and engagement in MR exergames and what design directions might support sustained participation. Phase 1 comprised a 10-day-long study using *ARWell PRO*, an MR exergame with 19 participants (6 DHH, 13 hearing) to understand both enablers and barriers to continued engagement for DHH users. Phase 2 built on these insights through design workshops with eight (1 DHH, 7 hearing) participants, where we collaboratively explored accessibility features and design concepts aimed at supporting sustained motivation and engagement. Phase 3 involved feedback sessions with 11 participants (4 DHH, 7 hearing) from Phase 1, to gather responses to static visual mockups. These mockups served as design provocations to understand participant perspectives on how proposed features might influence their willingness to return to MR exergames. We included hearing participants in all phases of our study, which helped us to contextualize DHH-specific experiences within broader patterns of exergaming engagement while centering DHH perspectives in our analysis.

Our work makes three key contributions:

(1) We present a multi-phase study that combines a longitudinal user study with design workshops and concept evaluation to connect empirical insights with design exploration. While the 10-day study captures how accessibility needs evolve over repeated use, subsequent phases extend these findings by translating them into accessible design concepts.
(2) We provide empirical insights into how DHH users experience accessibility features in MR exergames across repeated sessions. Our 10-day long study reveals moments where accessibility features that support initial learning become sources of frustration or cognitive load as familiarity increases, suggesting that accessibility needs in immersive exergaming are not static but evolve with repeated exposure.
(3) We offer a set of preliminary design directions and associated open research questions grounded in DHH participants' experiences and preferences, including managing instructional support, designing instructional modalities, designing for clarity without over-explanation, etc. While these directions remain conceptual and require further validation, they provide concrete, experience-based starting points for designers and researchers exploring accessibility for extended motivation and engagement, including and beyond immersive exergaming.

## 2 Background and Prior Work

### 2.1 Exergames and MR-based Exergames

Exergames are digital games designed to promote physical activity by translating players' physical actions, such as stepping, reaching, or bending, into game mechanics [55, 66, 105, 107]. This coupling of play and exercise has been shown to increase enjoyment [65], engagement [19], and adherence [51] compared to traditional exercise formats. However, most exergames remain screen-based, using controllers, cameras, or wearable sensors for movement detection and visual or audio feedback within a fixed viewpoint and movement space.

MR exergames blend digital content with the user's physical environment [57, 58] using head-mounted displays or mobile devices to overlay virtual elements onto real-world spaces [33, 82]. Virtual elements are spatially anchored to the real world, requiring users to navigate, reorient, and coordinate movement across their physical surroundings [35, 99], enabling more naturalistic, context-aware physical activity that blurs the boundary between gameplay and everyday movement [14]. MR exergames emphasize embodied interaction and spatial awareness that extend beyond what screen-based or controller-based exergames typically support.

While prior work demonstrates the potential of MR exergames to support accessible and engaging physical activity, comparatively little attention has been paid to how accessibility features within these systems shape users' motivation and engagement across repeated use.

## 2.2 Accessibility in MR for DHH Users

Research on accessibility in MR for DHH users has been conducted across various application domains. Common contexts include education and learning environments [71, 81, 92], workplace collaboration and training, collaborative and social MR systems [118], and entertainment or gaming experiences [69, 115]. These studies often explore how MR systems can support communication, understanding, and coordination with unavailable or limited auditory information [69].

A substantial body of prior work has focused on compensating for auditory information through visual substitutes, including real-time captions [47], speech-to-text overlays [81], and visual indicators of audio events [71, 93], to support comprehension during social, instructional, and collaborative interactions. Beyond text, researchers have explored non-textual visual cues, including icons, animations, color changes, and spatial metaphors, to convey information typically carried by sound [42, 48, 63]. Virtual characters and avatars have also been used to demonstrate actions, provide feedback, or communicate affect through expressive movement [25, 52, 71, 115]. While haptic feedback has been explored as a complementary modality [49, 70], visual channels remain the primary focus in DHH accessibility work for MR.

Much of this research evaluates whether accessibility features enable DHH users to understand content, follow instructions, or complete tasks; typically assessing initial usability or task performance in controlled or short-term settings. While this has established important foundations, it has largely emphasized access at the moment of interaction rather than how accessibility features are experienced across repeated use or extended engagement.

## 2.3 Motivation, Longitudinal Engagement, and Habit Formation in Exergames

Understanding why players begin, maintain, or abandon engagement has long been a central concern in game studies and HCI [17, 23, 91]. Self-Determination Theory (SDT) distinguishes intrinsic motivation, driven by inherent satisfaction and linked to autonomy, competence, and relatedness, from extrinsic motivation driven by external rewards [96], with intrinsic motivation being especially important in exergaming, where sustained activity depends on engagement beyond short-term incentives.

Engagement is understood as sustained involvement characterized by continued interest, focused attention, and immersion [24, 99]. Self-efficacy, players' confidence in performing game tasks, shapes motivation, persistence, and re-engagement [7]; while Social Cognitive Theory (SCT) frames motivation more broadly as the product of ongoing interactions between personal beliefs, in-game actions, and environmental feedback [8].

Studies across mobile, console-based, and sensor-driven exergames show that embedding physical activity within gameplay can increase enjoyment, perceived competence, and willingness to exercise [60, 74, 103]. However, engagement is not static; longitudinal work shows that initial motivation is often novelty-driven, particularly in immersive systems, and declines as familiarity increases [74, 87]. This "plateau" effect suggests that early enthusiasm may mask underlying usability or design limitations, making novelty alone insufficient for sustaining participation.

As a result, sustained engagement has been linked to habit formation, where repeated interaction becomes integrated into users' routines [22, 77], with long-term adherence depending on goal-setting, feedback, self-regulation [28, 64], and reducing interaction friction as skills evolve [22, 77]. Effective exergame design must therefore support transitions from exploratory to more efficient and autonomous use, rather than relying on novelty alone.

Comparative studies suggest that head-mounted displays can enhance presence, flow, enjoyment, and perceived exertion relative to traditional screens [15, 99], while avatar representation, self-competition, and performance augmentation further influence effort and intrinsic motivation [9, 16, 56]. Research on feedback and social dynamics, including virtual coaches, emotional expression, and competition, similarly shows that expressive feedback and social comparison can enhance motivation, though effects vary by user and context [41, 88, 103].

While prior work has examined motivation, longitudinal engagement, and habit formation through gameplay mechanics and behavior, limited attention has been paid to how accessibility needs evolve across repeated interaction. For DHH users in particular, accessibility is often treated as a static requirement addressed at a single point in time. We argue instead that accessibility is a dynamic process that evolves alongside users' familiarity and engagement trajectories, shaping both initial access and sustained participation.

## 3 Overview of Study Design

Our research followed a three-phase structure: (i) an initial 10-day-long user study and semi-structured interview, (ii) a design workshop and prototyping, and (iii) feedback on the visual mockups through participant interviews. Each phase involved its own recruitment process, supplemented by inviting participants from earlier phases to return, ensuring both fresh perspectives and continuity of DHH user-centered insight. Table 1 shows an overview of our study phases, including participants, methods, and purposes of each phase.

Our three study phases were analytically connected, with outputs from each phase informing the next. Phase 1 generated empirical insights into how motivation, accessibility needs, and interaction strategies evolved over repeated use, which were analyzed into key themes and design tensions. In Phase 2, participants and designers translated these findings into design concepts, low-fidelity prototypes, and visual mockups. Phase 3 gathered participant feedback on visual mockups to examine how the proposed designs addressed the temporal and accessibility challenges identified in Phase 1. This structure moved from empirical observation to co-designed concepts and reflective evaluation, grounding our design contributions in participants' lived experiences.

Moreover, our predominantly qualitative approach was well-suited to capturing participants' lived experiences and evolving motivation and accessibility needs. It enabled us to examine nuanced, context-dependent changes across repeated use that quantitative measures alone may not capture.

Table 1. Overview of the three study phases (participants, methods, and purpose)

| | **Phase 1** | **Phase 2** | **Phase 3** |
|---|---|---|---|
| **Who** | - 6 DHH participants<br>- 13 hearing participants | - Game design experience: 5 participants (1 DHH, Phase 1)<br>- No game design experience: 3 participants (all Phase 1) | - 4 DHH participants<br>- 7 hearing participants (all 11 participants from Phase 1) |
| **Who** | 10-day-long user study and semi-structured interview | Design workshop | Feedback interview on visual mockups |
| **Why** | Identify accessibility and motivation factors for DHH players through repetitive use | Co-design potential solutions addressing Phase 1 barriers for DHH participants | Explore participant responses to design concepts |

Our study included both DHH and hearing participants to distinguish accessibility-specific experiences from broader usability patterns while centering DHH perspectives. A more detailed explanation of our DHH-centered analytical approach is provided in Section 4.4.2.

### 3.1 Ethics Statement

This study was approved by the Institutional Review Board (IRB) of the first author's affiliated institution. Prior to participation in each phase, participants were informed about the study procedures, expected activities, and compensation and provided written informed consent. For example, in Phase 1, participants were informed that the study involved performing short standing exercises over a 10-day period and were only enrolled if they indicated comfort with these requirements. In Phase 2, participants were informed that artifacts generated during the workshop (e.g., sketches and design ideas) would be used to develop visual mockups and may be included in research publications. In addition to written consent, verbal consent was obtained prior to any audio or video recording of study sessions, including interviews and workshops. Participants were informed that they could withdraw from the study at any time without penalty.

## 4 Phase 1: 10-Day User Study and Interview

The first phase of the study was divided into two main segments, which were (i) a 10-day-long gameplay session involving three MR activities from the *ARWell PRO* [5] application, followed by a daily survey after each session, and (ii) a semi-structured interview conducted after the end of the gameplay period. We selected a consecutive 10-day study period as a short-term longitudinal window that would allow participants to move beyond a single first-use experience and engage with the MR exergame across repeated sessions [53, 110].

The 10-day duration was designed to capture early shifts in motivation, familiarity, accessibility needs, and interaction strategies as participants moved from initial exposure to repeated use, while limiting participant burden in a home-based study. Although insufficient to assess stable habit formation or long-term adherence, it allowed us to examine early engagement trajectories and how accessibility needs emerge and evolve across repeated sessions.

### 4.1 Study Probe

*ARWell PRO* is a guided MR exercise application for tablets, laptops, and smartphones, optimized for large screens (10 inches or greater) to ensure full-body visibility. Users position themselves approximately six to nine feet from the screen to enable accurate body movement capture (Figure 1). By using motion capture technology, the game lets the user use their limbs (e.g., head, arms, legs, etc.) as the game controller.

Participants were also given the option of connecting their device to an external monitor to enhance visual accessibility.

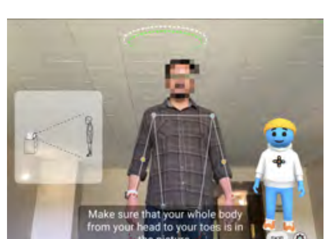
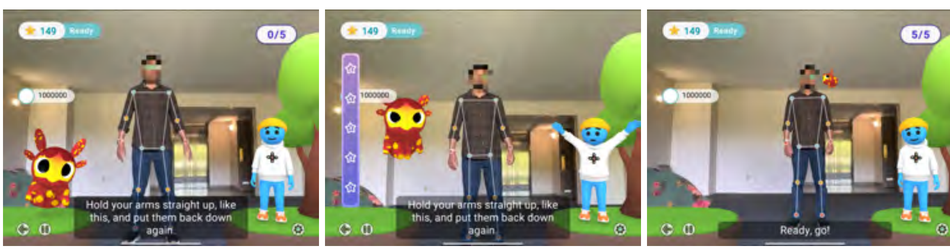



Fig. 1. Calibration screen before each of the activities.

Through a research partnership with *Augment Therapy* [4], we accessed three *ARWell PRO* activities that were in development at the time of the study. Each activity featured two virtual entities: a trainer, who provided verbal instructions with closed captioning (CC), and Peridot, a virtual character that acted either as a competitor or a companion depending on the activity. The three activities were: (i) *Hide and Seek:* players raced to locate the trainer before Peridot, using a “hot and cold” visual meter to gauge proximity (Figure 2); (ii) *Mini Squats:* players selected a target number of squats, with the trainer giving real-time guidance as Peridot appeared alongside them (Figure 3);

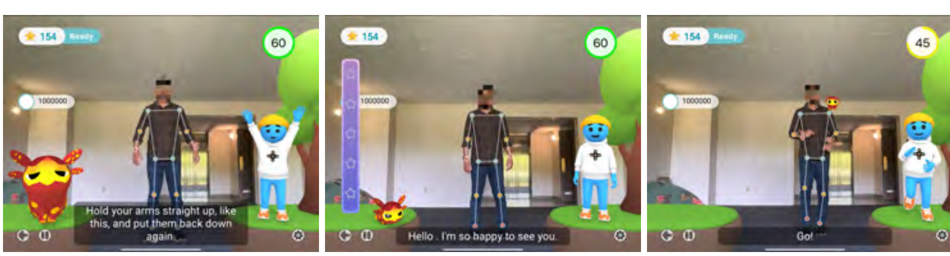

(a) Stadium (b) City (Guided) (c) City (Free)

Fig. 2. Three modes of *Hide and Seek*.




(a) Mode 1 (b) Mode 2 (c) Mode 3

Fig. 3. Three modes of *Mini Squats*.




(a) Mode 1 (b) Mode 2 (c) Mode 3

Fig. 4. Three modes of *Run In Place*.

and (iii) *Run in Place:* players ran in place for one minute at their chosen pace, supported by posture guidance from the trainer while Peridot was also present (Figure 4). Each activity offered three distinct modes, with further details provided in Table 6 of Appendix A. It is important to note that the available modes and Peridot's role across activities were defined by the application and could not be modified. However, players could turn off the verbal instructions and CCs if they wanted.

Upon completing each round of these activities, players would receive star rewards as points based on their performance. These three activities were compatible with newer-generation iPads, iPad Pros, iPad Airs, and MacBooks with M1 chips.

We selected *ARWell PRO* as a probe because it captures core MR exergaming features, including multimodal feedback, gesture-based interaction, real-time visual overlays, and support for sustained motivation in authentic home settings. Its diverse activities enabled us to examine varied interaction patterns while providing greater ecological validity than custom prototypes or head-mounted alternatives [27, 36, 80]. We used it as a practical, deployable platform to understand what shapes DHH participants' motivation and re-engagement across repeated sessions and to explore design concepts for longer-term engagement.

## 4.2 Participants

Participants were recruited through a combination of campus flyers, email outreach, and social media posts directed toward both hearing and DHH community groups. Interested people filled out a registration form from which we collected demographic data, hearing status, pronoun preference, device access, and willingness to complete 10 days of physical activity. All interested participants were contacted and provided with a consent form along with details of the study setup. Among them, 13 hearing and six self-identified DHH participants aged 20 to 59 enrolled for the user study, including four Deaf and two hard-of-hearing people. All hearing participants preferred spoken English as their primary method of communication, while three of the DHH people preferred ASL, and three preferred spoken English. Detailed demographic information is provided in Table 2.

Table 2. Demographic Information of Participants from 10-day User Study and Interview (Phase 1).

| Participants' ID | Gender | Age | Identified As | Preferred Mode of Communication |
|---|---|---|---|---|
| P01 | Male | 20 | Hearing | Spoken English, Written English |
| P02 | Male | 21 | Hearing | Spoken English, Written English |
| P03 | Female | 24 | HoH | Spoken English, Written English |
| P04 | Female | 24 | Hearing | Spoken English, Written English |
| P05 | Male | 22 | HoH | Spoken English, Written English |
| P06 | Female | 18 | Hearing | Spoken English, Written English |
| P07 | Female | 25 | Hearing | Spoken English, Written English |
| P08 | Male | 28 | Hearing | Spoken English, Written English |
| P09 | Female | 59 | Deaf | ASL, Written English |
| P10 | Male | 31 | Hearing | Spoken English, Written English |
| P11 | Female | 25 | Hearing | Spoken English, Written English |
| P12 | Male | 28 | Hearing | Spoken English, Written English |
| P13 | Male | 36 | Deaf | ASL, Written English |
| P14 | Male | 23 | Hearing | Spoken English, Written English |
| P15 | Female | 30 | Deaf | Spoken English, Written English |
| P16 | Male | 27 | Deaf | ASL, Written English |
| P17 | Male | 33 | Hearing | Spoken English, Written English |
| P18 | Male | 28 | Hearing | Spoken English, Written English |
| P19 | Male | 29 | Hearing | Spoken English, Written English |

## 4.3 Procedure

Following recruitment, each participant received an informed consent form outlining their rights and the expectations of the study. After consent had been given, researchers created individual accounts for each participant and provided personalized QR codes for logging into the *ARWell PRO* application.

Participants were instructed to complete a randomized set of activities per day for 10 consecutive days at a location of their choice. Each session consisted of all three MR activities. A daily survey link was emailed with activity instructions, followed by two reminder emails to prompt timely completion. Participants were asked to complete the activities and survey within 24 hours and report any technical or usability issues. Participants were asked to begin the study with the app's default settings enabled, including music, sound, and narration. Upon completion of the 10-day gameplay period, participants were invited to take part in a remote, semi-structured interview conducted via video conferencing.

Interpreters were made available for participants who preferred American Sign Language (ASL). During the interview, participants were asked to reflect on their motivational experiences throughout the study, factors that influenced their desire to engage or disengage, and challenges they encountered. Interview questions also probed unusual or noteworthy events that participants mentioned in their survey responses. Each participant received a $50 e-gift card as compensation upon completing both the gameplay and interview phases of the study.

### 4.4 Data Analysis

To support our study design, we tracked participants' gameplay logs across the 10-day period. This allowed us to verify task completion and cross-check self-reported survey responses against actual in-game behavior, reducing discrepancies between reported experiences and observed engagement. Daily surveys served as reflective diaries, capturing immediate reactions and experiences, which informed the development of our semi-structured interview questions.

*4.4.1 Analytic Process.* Semi-structured interviews were our primary qualitative data source. All interviews were audio-recorded and transcribed. The first author verified transcript accuracy by comparing them against audio recordings before analysis.

We conducted reflexive thematic analysis (RTA) [18] using MAXQDA [113], engaging with the data at semantic (surface-level) and latent (underlying) levels to interpret patterns in motivation, engagement barriers, and accessibility experiences. Consistent with RTA, we developed themes through iterative, reflexive engagement rather than treating them as emerging from the data.

The first author conducted initial inductive coding of all interview transcripts, generating codes such as "captions helpful initially," "Peridot as companion," and "unclear hot/cold meter." The second and last authors engaged in iterative discussions with the first author to reflect on interpretations, challenge assumptions, and refine developing themes. Rather than seeking consensus, these discussions supported reflexive engagement with the data and deepened the interpretive analysis.

Through iterative cycles of coding, reflection, and discussion, the research team developed themes that captured patterns in participants' experiences. Codes were used as analytic tools to support the construction and refinement of these themes, rather than as fixed categories. The analysis resulted in 129 refined codes, which informed six subthemes and three overarching themes. Table 3 provides an overview of the thematic structure.

*4.4.2 Centering DHH Experiences.* While our study included fewer DHH participants than hearing participants, we prioritized DHH participants' experiences as the primary interpretive lens for understanding accessibility-related themes. This approach aligns with established practices in accessibility research, where in-depth qualitative insights from smaller samples of marginalized users often reveal critical design considerations [70, 102].

Furthermore, we used hearing participants' data to provide context, rather than allowing their experiences to dominate our analysis. For example, when DHH participants described captions as "overwhelming" after repeated use, while hearing participants did not mention visual load concerns, we interpreted this as an accessibility-specific pattern rather than a general usability issue.

Moreover, we explicitly identified where DHH and hearing experiences converged (e.g., both groups appreciated character encouragement) and diverged (e.g., only DHH participants reported

Table 3. Overview of Thematic Analysis from Phase 1 Findings.

| Themes | Sub-themes | Example Codes |
|---|---|---|
| 1. Evolving Roles of Accessibility Features Over Time | 1.1 From Initial Guidance to Cognitive Overload<br>1.2 Spatial and Positional Trade-offs | "Captions helpful initially," "Repeated reading of captions," "Had to move back and forth to see instructions," "Captions blocking game elements," "Onboarding felt long after day 5," etc. |
| 2. Shifting Effects of Virtual Characters' Guidance and Feedback | 2.1 Embodied Interactions<br>2.2 From Novelty to Fatigue Over Time | "Trainer mirroring clarifies what to do," "Peridot creates companionship," "Character gestures replace audio cues," "Peridots' behaviors become predictable," "Want more responses from virtual charecters," "Static interactions of Peridot lose appeal," etc. |
| 3. Limitation in Multimodal Feedback | 3.1 Challenges Interpreting Visual Cues<br>3.2 Challenges With Dense Visual Guidance | "Unclear hot/cold meter," "Navigation arrows too subtle," "Lack of directional guidance," "Too much on screen at once," "Suggestions for enhancements," etc. |

cognitive fatigue from sustained visual attention). This enabled us to distinguish accessibility barriers from general usability challenges while keeping DHH perspectives central to our analysis.

## 4.5 Findings

We identified three overarching themes that capture how accessibility features and game design elements shaped DHH users' motivation across repeated interactions with the MR exergame. We found these themes by examining how participants' experiences—especially those of DHH participants—changed over the 10-day study period, as well as the factors that supported or discouraged continued engagement over time.

### *4.5.1 **Theme 1: Evolving Roles of Accessibility Features Over Time.***

***i) From Initial Guidance to Cognitive Overload:*** All DHH participants (6/6) reported that captions were essential for comprehension during the early sessions (Days 1–4), particularly when learning new exercises and transitioning between activities. P05 (HoH) noted:

> *"I found the closed caption to be very useful, accurate, and easy to get."* [P05, HoH]

Participants described captions as reducing uncertainty about required actions, allowing them to focus on movement execution rather than task interpretation. Together, captions, onboarding instructions, and visual guidance supported early orientation and built confidence. These forms of visual support were particularly important before participants became familiar with the system.

However, by the mid to late phase of the study (Days 5–10), features that initially supported clarity began to affect engagement in a negative way. Five of six DHH participants described captions and repeated instructions as increasingly burdensome during routine gameplay, especially after becoming familiar with the exercise structure. P15 (Deaf) explained:

> *"The onboarding process seemed very long especially in the later half of the [user study] period [...]. All the instructions (in captions) were the same, but it felt longer probably because I was going through the same thing over and over again."* [P15, Deaf]

This shift reflects how participants' experience of the same support features changed over time. While hearing participants (9/13) also reported fatigue from repeated audio instructions, DHH participants faced additional visual demands from rereading captions and rewatching demonstrations. As a result, repeated instructions increased rather than reduced cognitive load for DHH users.

***iii) Spatial and Positional Trade-offs:*** Caption placement remained a persistent accessibility challenge throughout the study, particularly during Days 5–10. All DHH participants (6/6) reported that fixed captions forced them to shift between reading instructions and maintaining gameplay posture, especially during movement-intensive activities. P03 (HoH) described:

> *"I had to move forward to read the closed captions properly, but when I do so, the app tells me to back away."* [P03, HoH]

In addition, four of six DHH participants reported that large caption blocks obscured important visual elements during fast-paced gameplay. As gameplay accelerated, captions shifted from supporting comprehension to competing for visual attention, causing frustration and disrupting focus. Because captions remained a primary information source, their placement was critical to both understanding and physical execution.

#### 4.5.2 *Theme 2: Shifting Effects of Virtual Characters' Guidance and Feedback*.

***i) Embodied Interactions:*** The trainer's mirrored demonstrations provided accessibility through embodiment rather than text alone. Five of six DHH participants reported that watching the trainer perform movements clarified expectations more effectively than captions. P09 (Deaf) noted:

> *"Instructions were pretty accurate to begin with [...]. It became even clearer when the blue trainer was working along with me."* [P09, Deaf]

This embodied guidance reduced dependence on linguistic processing and allowed participants to understand through observation—a particularly valuable modality for DHH users.

Additionally, Peridot served as an emotional and social companion, providing non-verbal feedback that helped compensate for the absence of auditory ambiance. Through playful interactions, such as jumping on participants' shoulders or engaging in *Hide and Seek*, players found it to be "funny," "cute," and motivating. These visually mediated interactions reduced feelings of isolation and fostered emotional engagement without relying on sound.

Notably, appreciation for character interactions extended across hearing status. Both DHH and hearing participants valued Peridot's presence, indicating that multimodal, visually rich feedback can enhance engagement for a broad range of users. However, the role the character played differed subtly: DHH participants emphasized how Peridot compensated for the absence of audio cues, while hearing participants framed the interaction primarily in terms of entertainment. This contrast highlights how the same design feature can serve both accessibility and engagement.

***ii) From Novelty to Fatigue Over Time:*** In the latter part of the study (Days 5–10), four of six DHH participants noted that character behaviors felt predictable and static. P03 (HoH) reflected:

> *"I liked that Peridot jumped on my shoulder at a point and it was funny at first [...]. But I would like it even better if it had some other actions, especially ones like reacting to what I was doing."* [P03, HoH]

Similar patterns were observed among hearing participants, seven of whom described the trainer's monotone voice as "robotic." One HoH participant with residual hearing (P05) noted:

> *"Even though I mostly relied on closed captions and guidance from the trainer, I could partially hear sound [...]. The voice of the trainer was getting a little annoying after a while."* [P05, HoH]

Together, these accounts show how repeated exposure to static feedback reduced engagement over time. For DHH participants, particularly those with residual hearing, this predictability was experienced across both visual and auditory channels, limiting opportunities for variation or adaptation in the primary modalities they relied on for interaction.

#### 4.5.3 *Theme 3: Limitation in Multimodal Feedback.*

***i) Challenges Interpreting Visual Cues:*** In Hide and Seek, ten participants (4/6 DHH, 6/13 hearing) initially missed the purpose of the "hot and cold" meter, particularly during early gameplay when the mechanic was first introduced. P16 (Deaf) described this ambiguity:

> *"I noticed it at the corner of the screen, but couldn't figure out how it worked."* [P16, Deaf]

Hearing participants reported relying on Peridot's subtle auditory cues (e.g., cooing sounds) when it moved out of view. These sounds helped them relocate Peridot, find the trainer, and gradually associate changes in the meter with their proximity to the target. In contrast, DHH participants lacked an equivalent secondary channel. When Peridot moved out of view, they had to search the environment without additional guidance, as neither the "hot and cold" meter nor Peridot provided accessible cues for reorientation.

Furthermore, for DHH participants, the visual indicator remained unclear across sessions, requiring continued interpretation and guesswork. This unresolved ambiguity extended into "City (Free)" mode, where thirteen participants (5/6 DHH, 8/13 hearing) reported feeling disoriented due to limited directional guidance in the open-ended environment. P03 (HoH) noted:

> *"I probably struggled the most with the 'City (Free)' mode [...]. No matter which direction I moved towards, it felt like I was going farther away from the trainer."* [P03, HoH]

While hearing participants could again rely on Peridot's auditory cues to orient themselves—sometimes instead of attending to the "hot and cold" meter—DHH participants lacked equivalent visual support to confirm directionality. As a result, brief moments of confusion were more likely to persist for DHH participants, leading to prolonged disorientation and reduced confidence in navigation.

Additionally, seven participants (3/6 DHH, 4/13 hearing) reported that they did not notice the directional arrows in City (Guided) mode until these were explicitly discussed during the interview. When asked why the arrows went unnoticed, DHH participants explained that they interpreted them as part of the general game environment rather than as meaningful navigational cues. This suggests that, in the absence of explicit visual framing, DHH users may treat unfamiliar visual elements as decorative or ambient rather than instructional. In contrast, hearing participants reported that they primarily followed Peridot's auditory guidance, which reduced their reliance on—and attention to—separate visual navigation indicators. Collectively, these experiences of DHH participants further solidified the fact that when visual cues lack clear meaning or reinforcement, ambiguity for DHH users can persist across gameplay contexts rather than resolving with experience.

***ii) Challenges With Dense Visual Guidance:*** Challenges arose in visual guidance during setup and gameplay, particularly during calibration. Several DHH participants (4/6) described calibration screens as overwhelming when multiple instructions were presented simultaneously. As P05 (HoH) explained:

> *"It felt like way too much going on at the same time [...] I would prefer dividing them into separate screens."* [P05, HoH]

Participants reported that dense visual instruction increased cognitive effort during setup by requiring simultaneous reading, interpretation, and physical adjustment. For DHH users relying on visual guidance alone, multiple instructions made calibration more demanding than supportive.

## 5 Phase 2: Design Workshop and Static Visual Mockup Design

The second phase involved a design workshop aimed at generating ideas to improve the exergame experience and support motivation and re-engagement for DHH users over repeated interactions. We recruited participants through two channels: (i) senior-level students majoring in game design,

Table 4. Demographic Information of the Participants from the Workshop (Phase 2).

| Group | Assigned Activity | Participants' IDs | Has Game Design Expertise? | Participated in Phase 1? | Identified As |
|---|---|---|---|---|---|
| 01 | Mini Squats | WP01 | Yes | No | Hearing |
| | | WP02 | No | Yes | Hearing |
| 02 | Run In Place | WP03 | Yes | No | Hearing |
| | | WP04 | Yes | Yes | HoH |
| | | WP05 | No | Yes | Hearing |
| 03 | Hide and Seek | WP06 | No | Yes | Hearing |
| | | WP07 | Yes | No | Hearing |
| | | WP08 | Yes | No | Hearing |

identified through flyers and email outreach at a local college; and (ii) previous participants from the 10-day user study to ensure continuity and user-centered insight.

In Phase 2, we intentionally included game design students to translate Phase 1 findings into feasible interaction and interface concepts. While Phase 1 identified accessibility and engagement challenges, operationalizing these insights required expertise in game mechanics, spatial interaction, and XR interface design. Game design students provided this expertise, complementing DHH participants' lived experiences and the research team's interpretive role.

Our goal was to form three groups, each consisting of two to four members, with a deliberate mix of game design expertise and first-hand player experience. This structure ensured each group included at least one participant familiar with game design principles and one who completed the full Phase 1 gameplay period.

Each group was tasked with discussing potential design enhancements for the overall app, as well as one specific activity within the game. To support this ideation process, we provided worksheets for participants to sketch or write down their concepts collaboratively. We prioritized prototyping ideas that aligned with Phase 1 findings. These prioritized concepts were then developed into visual mockups, which informed the evaluation phase of the study.

### 5.1 Participants

We recruited a total of eight participants for the workshop. The group included:

- Four participants with game design expertise who had no prior experience with the app or its activities,
- Three participants who had previously completed the 10-day user study (Phase 1), and
- One DHH participant who was both a game design expert and a returning user from Phase 1. Notably, this participant was HoH, and he preferred spoken English as the primary mode of communication.

Although DHH participation in this phase was limited, their input grounded the design process, while design students supported the development of implementable concepts.

See Table 4 for more details about the participants.

### 5.2 Procedure

All workshop sessions were conducted in person by the first author in a conference room setting. Each workshop session lasted approximately two hours and was scheduled based on participant availability.

At the beginning of each session, participants received a brief introduction to the app, the specific activity their group would focus on, and the overall goals of the workshop. Participants who were unfamiliar with the app were asked to try out the assigned activity to gain a comprehensive understanding. For returning participants, this interactive session was optional, but encouraged to refresh their memory of the activity.

Following this, participants were provided with worksheets to support the design process. We then introduced the accessibility and engagement challenges identified in Phase 1, organized into generalized and activity-specific barriers. Participants who had taken part in the earlier study were asked to reflect on whether these challenges aligned with their own experiences.

The workshop proceeded in a series of timed design rounds. For each challenge, participants were asked to (1) describe the issue in their own words, (2) propose potential solutions, and (3) sketch low-fidelity interface or interaction ideas illustrating how these solutions might be implemented in the application. Each round lasted approximately five minutes.

After each round, participants presented their ideas and explained their rationale. This was followed by a group discussion, where participants were encouraged to comment on and build upon each other's proposals. These discussions allowed us to capture both individual design ideas and collective reflections on how the proposed solutions addressed the identified challenges. A few instances of the worksheet with low fidelity design ideas are illustrated in Figure 5.

All sessions were audio and video-recorded. Participants received a $30 e-gift card as compensation for their time and contributions. Following the workshop, we analyzed the collected data, participant-generated ideas, and design artifacts to develop a set of visual mockups for the next phase of the study.


(a) (b) (c)

Fig. 5. Three instances of low-fidelity design ideas from the design workshop.

### 5.3 From Workshop to Mockups

The first author analyzed the design proposals by prioritizing concepts that addressed DHH participants' expressed needs and the key findings from Phase 1. Ideas were selected for prototyping based on three criteria: (1) direct alignment with barriers identified in Phase 1, (2) strong support or consensus among group members with different expertise (including game design students and Phase 1 participants), and (3) potential to address DHH-specific accessibility challenges while supporting sustained motivation and engagement.

The first author developed the prioritized concepts into static, visual mockups using Procreate [98], Canva [20], and Google Slides [40]. These visual mockups illustrated proposed interface changes, customization options, character behaviors, and feedback mechanisms. The first author then met with the second, third, and last authors multiple times to review the designs and assess whether they were appropriate and sufficiently comprehensive for Phase 3.

Following group consensus, the mockups were finalized with minor refinements, including adjusted font sizes and clearer instructional prompts. These image-based mockups served as design prompts in Phase 3, enabling feedback on key concepts before full system development. Figure 6 illustrates how the Phase 2 findings align with the themes and subthemes identified in Phase 1.

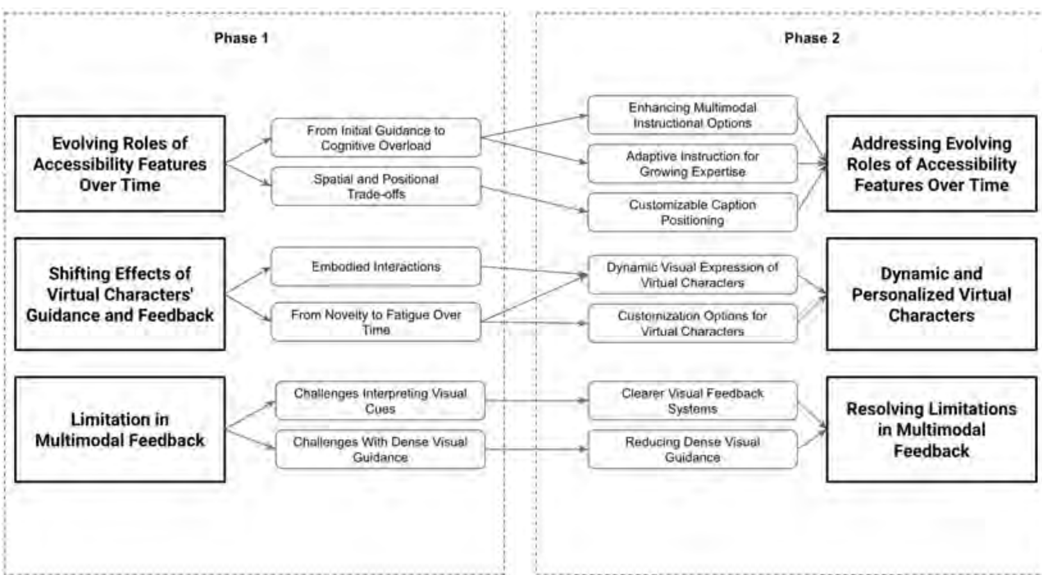


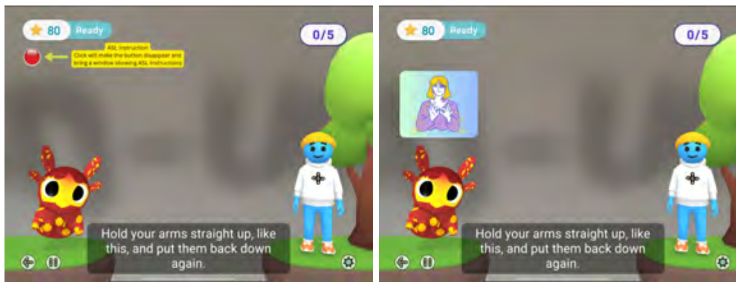

Fig. 6. Overview of alignment between Phase 1 themes and subthemes and Phase 2 design concepts.

## 5.4 Findings

While Phase 1 focused on identifying factors that influenced DHH participants' motivation and re-engagement across repeated use, Phase 2 shifted toward collaboratively exploring design concepts that responded to these factors, specifically the identified challenges. We organized the Phase 2 findings around the three main themes identified in Phase 1, illustrating how the proposed visual mockups were grounded in the earlier findings.

*5.4.1* ***Theme 1: Addressing Evolving Roles of Accessibility Features Over Time.*** Phase 1 showed that features that were helpful initially became burdensome over time, leading to cognitive overload and spatial conflicts. Workshop participants proposed adaptive solutions that allow accessibility features to evolve with user expertise.

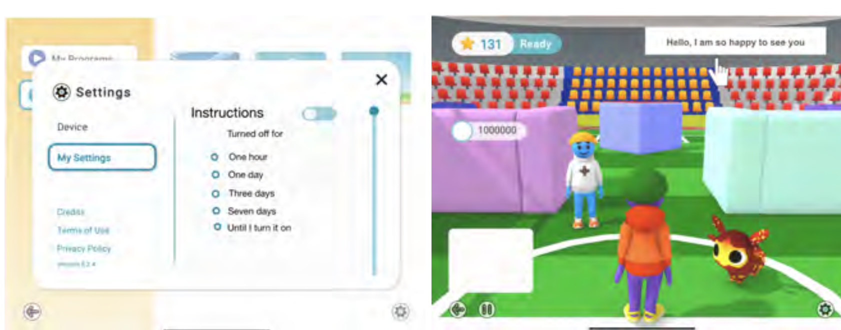
***i) Enhancing Multimodal Instructional Options:*** While captions supported comprehension in Phase 1, they required sustained visual attention and occasionally disrupted flow (Subtheme 1.1). To provide an additional, more natural modality, participants proposed integrating pre-recorded sign language (SL) videos for each activity (Figure 7). These clips could be activated through a virtual button, enabling players to review visual task demonstrations on demand without disrupting immersion. For Deaf users who prefer SL, this creates a more equitable instructional channel; for others, the ability to opt out prevents redundancy.




(a) (b)

Fig. 7. A set of visual mockups displaying (a) a virtual button in an activity with explicit instruction about what it does, and (b) when the button is tapped, a screen appears where instructions are iterated in SL and can be accessed on demand.

***ii) Adaptive Instruction for Growing Expertise:*** Phase 1 showed that repeated instructions, while supporting initial comprehension, became cognitively taxing for DHH participants who had to reread captions or rewatch trainer gestures in every session (Subtheme 1.2). To address this temporal challenge, based on participants' suggestions, we designed a mockup (Figure 8a) allowing players to temporarily disable instructional guidance once familiar with activities. Users can mute instructions for customizable intervals—one hour, one day, one week, or until manually re-enabled—giving them control over guidance intensity as their expertise grows.



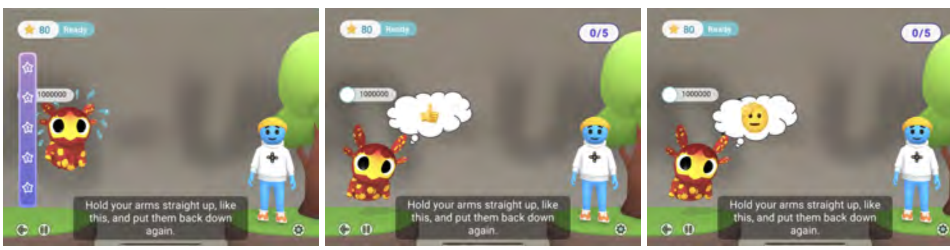

(a) (b)

Fig. 8. Visual mockups designed based on the idea to (a) prevent repetitions of instructions, and (b) show that the players can select the CC window and place it anywhere they want on the screen.

***iii) Customizable Caption Positioning:*** In Phase 1, DHH participants reported that static caption placement forced them to choose between reading instructions and maintaining gameplay posture, often obscuring critical visuals (Subtheme 1.2). Workshop participants proposed fully movable captions (Figure 8b), enabling players to reposition them via tap-and-drag for greater comfort and visibility.

*5.4.2* ***Theme 2: Dynamic and Personalized Virtual Characters.*** Phase 1 revealed that while virtual characters provided valuable instructions and social presence, their static behaviors led to fatigue over time. Workshop participants proposed making characters more expressive, adaptive, and personalizable.

***i) Dynamic Visual Expression of Virtual Characters:*** As Peridot's limited actions became predictable over repeated sessions (Subthemes 2.1 and 2.2), participants proposed making its responses more expressive and responsive to player performance (Figures 9a, 9b, 9c). Suggested behaviors included sweat droplets during intense activity, thumbs-up emojis for encouragement, and salutes for high scores.




(a) (b) (c)

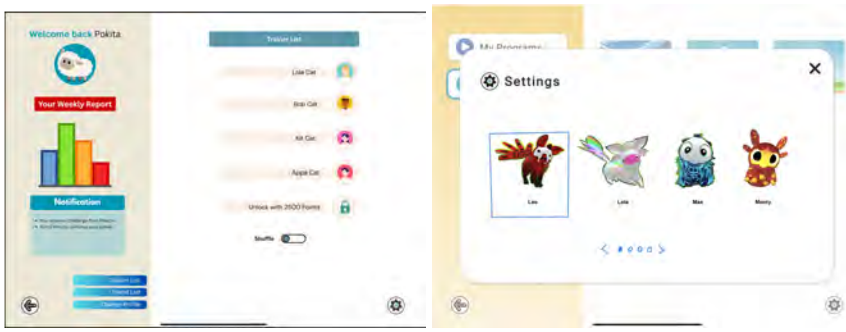
Fig. 9. A set of visual mockups where (a) Peridot is sweating because the player is performing the activities at a higher pace, (b) Peridot is showing the player a thumbs-up, and (c) Peridot is saluting the player as they surpass their own high scores.

***ii) Customization Options for Virtual Characters:*** The trainer's monotone voice, static visuals, and personality reduced motivation in Phase 1, especially for DHH participants who lacked alternative accessible channels once visual cues became repetitive (Subtheme 2.2). Workshop participants suggested an idea for a mockup (Figure 10a) introducing multiple trainer options with distinct visual styles, gestures, and personalities. Players can select a preferred trainer, enable "daily shuffle" mode for variety, or unlock additional trainer profiles using accumulated star rewards. The usage of the star rewards for unlocking new trainer personalities was an idea that explicitly came from participants who were also a part of Phase 1.

Similarly, participants suggested adding new customization options for Peridot, such as different visual styles to choose from, character evolutions based on user progress, or accessories and skins (Figure 10b). These additions would open new avenues for personalization through visual cues. In addition, these approaches provided a meaningful use for accumulated star rewards, which otherwise served no functional role in the game till this point.

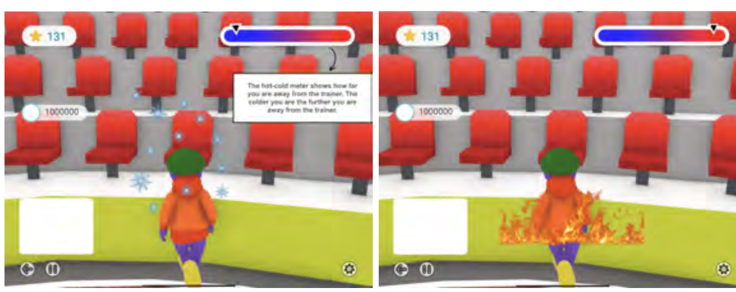
*5.4.3* ***Theme 3: Resolving Limitations in Multimodal Feedback.*** In Phase 1, we found that unclear visual indicators, subtle navigation cues, and dense visual guidance created disproportionate barriers for DHH participants relying entirely on visual channels. Workshop participants proposed enhancements to improve clarity, reduce cognitive load, and strengthen directional feedback.

***i) Clearer Visual Feedback Systems:*** The "hot and cold" meter was often overlooked by DHH participants in Phase 1 because its purpose was never explained and its cues were visually subtle (Subtheme 3.1). Workshop participants recommended explicit onboarding instructions paired with layered visual metaphors. For example, snow could fall on the player's avatar in the "cold" zone (Figure 11a), intensifying with distance, while flames could ignite in the "hot" zone (Figure 11b), growing stronger as players go closer to the trainer.




(a) (b)

Fig. 10. Visual mockup designed based on the idea to choose (a) a different trainer or put them on shuffle, and (b) their own version of Peridot from.




(a) (b)

Fig. 11. A set of visual mockups where (a) there is an explicit instruction for players about the “hot and cold” meter, snow is falling on the player’s avatar as they are far from the trainer, and (b) there is a flame around the player’s avatar to depict that they are very close to the trainer.

Additionally, Phase 1 revealed that subtle wooden arrows meant to guide players in “City (Guided)” mode were frequently missed by DHH participants, leading to disorientation. Participants suggested either glowing arrows with increased visual salience (Figure 12a) or a floating directional arrow above the player’s avatar persistently pointing to the goal (Figure 12b). Both options provide clear, continuous orientation without requiring auditory confirmation, directly addressing the navigation challenges identified in Phase 1.

Furthermore, the unguided map left many DHH participants feeling lost without auditory reassurance. Participants proposed an optional minimap showing player and trainer positions, toggleable based on preference (Figure 13), and randomly placed power-ups (e.g., speed boosts, “see-through-wall” abilities) to encourage exploration with visually communicated rewards.

***ii) Reducing Dense Visual Guidance:*** Phase 1 showed that initial calibration overwhelmed DHH players with simultaneous information, reducing clarity and increasing visual load (Subtheme 3.2). To address this, workshop participants proposed separating calibration into two phases: one screen for clear textual and visual instructions (Figure 14a) and another focused solely on calibration (Figure 14b). Directional indicators, such as arrows and body outlines (Figures 14c, 14d), would guide body tracking more efficiently, reducing trial and error for players relying on visual guidance.


(a) (b)

Fig. 12. Two options to enhance players' understanding of the mechanism of the wooden arrows, where (a) a wooden arrow is glowing, and (b) an arrow is placed just above the player's avatar.


Fig. 13. A visual mockup of the mode "City (Free)" where a minimap and a power-up (a backpack) are included.

## 6 Phase 3: Feedback Interview on Visual Mockups

The third phase involved gathering participant feedback on the static visual mockups developed in Phase 2. These mockups represented conceptual design concepts addressing the three key themes from Phase 1. Rather, in Phase 3, we used static visual mockups to gather participants' reflections on whether the proposed designs addressed the temporal accessibility and engagement challenges identified in Phase 1. By inviting Phase 1 participants to reflect on the designs in relation to their prior 10-day experience, we used the mockups to probe how proposed features might support repeated use, reduce accumulated visual effort, and sustain motivation over time.

### 6.1 Participants

We invited Phase 1 participants to participate in remote feedback interviews, recruiting eleven participants (4 DHH, 7 hearing) who agreed to continue. Including Phase 1 participants ensured continuity with those who had directly experienced the barriers, allowing them to assess whether proposed solutions aligned with their lived experiences. We included both DHH and hearing participants to examine whether DHH-focused design concepts might also benefit or complicate experiences for hearing users in mixed-group MR exergame contexts.

Among our eleven participants, seven were hearing, two were Hard of Hearing, and two were Deaf participants who preferred ASL as their primary mode of communication. Similar to Phase

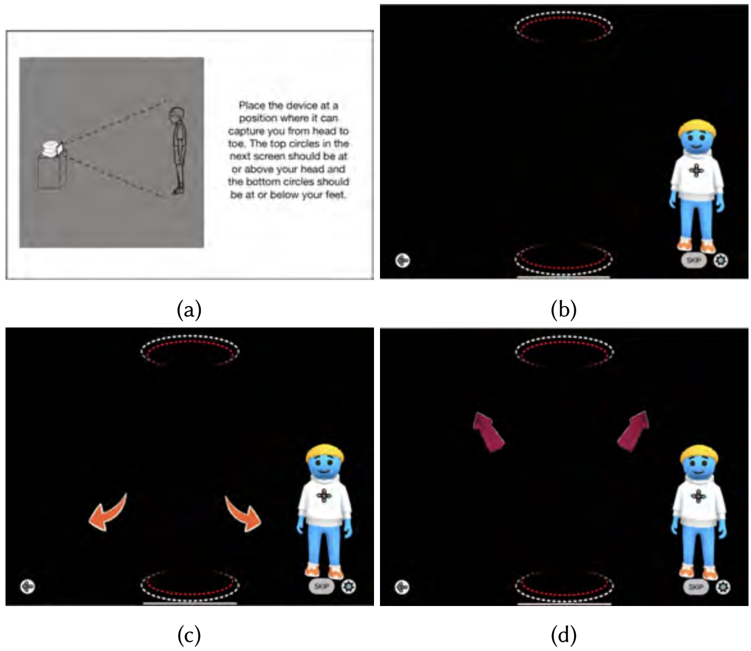



Fig. 14. A set of visual mockups showing a more accessible calibration approach where (a) shows visual and textual instructions, (b) shows a screen devoid of any instructions where the player takes action to calibrate their body with for the activities, (c) and (d) shows arrows as visual and directional cues to help the player to calibrate more smoothly.

Table 5. Demographic Information of Participants from Visual Mockup Evaluation Interview (Phase 3); where H = Hearing, HoH = Hard of Hearing, and D = Deaf. An asterisk (*) next to a participant ID indicates participation in Phase 2.

| Participants' IDs | EP01 | EP02 | EP03 | EP04 | EP05* | EP06* | EP07 | EP08 | EP09 | EP10* | EP11* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Identified As** | H | H | H | D | H | HoH | H | HoH | D | H | H |

1, we arranged ASL interpreters for communicating with those preferring ASL. Notably, all four participants who had also participated in Phase 2 returned for Phase 3, allowing for a valuable continuity of insight across all three phases of the study. More details about the participants in this phase are provided in Table 5.

## 6.2 Procedure

The interviews took place remotely via Zoom and lasted approximately one hour. We organized the mockups around the three Phase 1 themes and presented them sequentially via screen sharing. For each design, we first explained the specific barrier it addressed and then gathered feedback on its effectiveness, usability, and appeal. Participants were encouraged to think aloud as they reviewed each mockup, discussing what they found compelling, concerning, or missing. We asked participants whether each proposed feature would encourage continued exergame use across sessions, framing questions around sustained motivation and re-engagement rather than immediate appeal. In addition, participants were encouraged to suggest new ideas or alternatives they believed would work better for specific scenarios within the app or its activities. At the end of the interview, each participant received a $20 e-gift card as compensation for their time and input.

### 6.3 Data Analysis

Interview transcripts were transcribed and verified against audio recordings by the first author to ensure accuracy. Similar to Phase 1, we conducted reflexive thematic analysis (RTA) in MAXQDA, engaging with the data at semantic and latent levels to interpret participants' responses to the proposed design concepts. However, our analytical approach differed from Phase 1. Rather than developing themes from scratch, we analyzed Phase 3 data in relation to the three Phase 1 themes. The first author coded responses based on the barrier each mockup addressed, noting whether they aligned with lived experiences, raised new concerns, or revealed unexpected considerations.

The second and last authors reviewed coded segments and discussed patterns with the first author to refine thematic interpretations. These discussions supported reflexive engagement rather than building consensus. We particularly focused on how participants used Phase 1 experiences to evaluate proposed solutions against previously encountered barriers. We also recognized that static mockups supported hypothetical reflection but could not confirm how the designs would function in practice.

Through iterative cycles of coding, reflection, and discussion, we developed interpretations of how the proposed designs addressed, or failed to address, the temporal and accessibility-related challenges identified in Phase 1. The analysis involved 234 initial codes, which were refined to 107 codes through iterative engagement with the data.

As in earlier phases, we prioritized DHH participants' feedback when interpreting accessibility-focused design concepts while using hearing participants' feedback for contextual purposes. This approach helped distinguish features that addressed DHH-specific accessibility needs from those that reflected broader usability improvements.

### 6.4 Findings

Building on Phase 2's design concepts, in Phase 3 we explored how participants, particularly those who had experienced Phase 1 barriers firsthand, responded to static visual mockups. We organize findings according to the three Phase 1 themes, examining whether proposed designs resonated with participants' lived experiences.

#### *6.4.1* ***Responses to Adaptive Accessibility Features.***

***i) Toggleable Instructions and Movable Captions:*** All DHH participants (4/4) favored the mockup for temporarily disabling repetitive instructions. EP09 (Deaf) explained:

> *"I think it's actually a great addition, because a lot of time gets wasted in instructions [...] Even though I liked the instructions initially, I am glad that I don't have to keep looking for when the activities are actually starting."* [EP09, Deaf]

This response suggests the design aligned with Phase 1 experiences, where repeated content became burdensome over time. Notably, hearing participants (7/7) viewed this feature as improving time efficiency, whereas DHH participants experienced it as reducing cognitive load.

All DHH participants (4/4) agreed that repositionable captions could address Phase 1 spatial conflicts between reading instructions and maintaining gameplay posture. P04 (Deaf) directly connected the proposal to their earlier frustration:

> *"Sometimes the CCs blocked where I am [player's avatar] going before [in 10-day user study]. But now, I can maybe use the top part of the screen to place the CCs and see where I am going clearly."* [P04, Deaf]

These findings highlight flexible caption placement as a design concept that can reduce visual–spatial conflicts and support sustained engagement for DHH users in exergames.

***ii) Sign Language (SL) Video Instructions and Streamlined Calibration:*** All DHH participants (4/4) expressed interest in SL video instructions as an alternative to text-based guidance. EP09 (Deaf) noted:

> *"The instructions before [in textual form] were fine, but these [instructions in SL] are even better."* [EP09, Deaf]

For participants who use SL as their first language, this shift could reduce the need to mentally translate written English during gameplay. Presenting instructions in users' primary communication modalities may therefore improve comprehension, reduce cognitive effort, and support engagement.

Furthermore, three DHH participants favored the two-step calibration process, separating instructions from physical positioning over the previous version. P06 (HoH) explained:

> *"The arrows are a big help because I remember there were only top and bottom circles previously [...]. And I had to go over them a couple of times to understand how they work."* [P06, HoH]

Participants extended this concept beyond the mockups, proposing embodied trainer gestures during calibration to signal movements such as "come closer" or "step back." This suggests structured, visually guided calibration as a design approach for supporting sustained engagement through clear, repeatable setup routines.

### 6.4.2 *Responses to Enhanced Virtual Character Systems.*

***i) Customizing Virtual Characters:*** Three DHH participants valued the concept of multiple trainers with distinct personalities and visual styles. EP06 (HoH) explained:

> *"I like the idea of having different voices and personalities for the instructor. [...] And also, you have the option to customize it. And on different days, you can have new trainers."* [EP06, HoH]

This preference reflects how participants connected trainer variety with maintaining engagement over time, particularly in relation to previously identified limitations of static character behavior. Hearing participants (5/7) also welcomed trainer variety, but primarily for novelty and enjoyment, suggesting different interpretations of the same feature.

In addition, eight participants (4/4 DHH, 4/7 hearing) supported Peridot personalization options. EP08 (HoH) connected this to Phase 1's unclear reward mechanics:

> *"I would like to see that [evolving Peridot]. It would motivate me to do the activities more frequently if that's what's needed to make me grow [...]. Also, this is a good way to spend the earned stars, in my opinion."* [EP08, HoH]

Participants' responses suggest that personalization features were interpreted as a way to make reward mechanisms more meaningful, particularly for DHH users who rely on visual progression cues. By tying rewards to visible character changes, these features may support sustained engagement through accessible, non-auditory feedback over time.

***ii) Expressive Peridot Behaviors:*** All DHH participants (4/4) expressed enthusiasm for enhanced Peridot animations—sweating, emoji displays, reactive gestures—while hearing participants showed mixed reactions (2/7 positive, 4/7 indifferent). EP06 (HoH) stated:

> *"I like that it [Peridot's reaction] is more animated with the sweat [...]. And it's definitely a good idea to use emoji, because everyone knows these [emojis]."* [EP06, HoH]

The emphasis on emojis as universal visual symbols reveals how DHH participants viewed these features as accessible emotional communication operating through their primary sensory channel.

#### 6.4.3 *Responses to Enhanced Multimodal Feedback.*

***i) Explicit Game Mechanic Instructions and Progressive Visual Metaphors:*** All DHH participants (4/4) supported explicit onboarding for the "hot and cold" meter. EP04 (Deaf) explained:

> *"I agree with this (explicit instruction about the meter), because at the top, you can see the bar, but don't realize what it is for. It took me several days to realize what its purpose was."* [EP04, Deaf]

By referring to the delay in understanding ("several days"), EP04 highlighted how the absence of explicit visual explanation prolonged uncertainty for DHH participants. Without incidental auditory cues that might clarify ambiguous mechanics, DHH users relied more on clear, upfront visual onboarding for timely understanding.

Similarly, all DHH participants (4/4) valued layered visual cues such as falling snow (indicating distance from the trainer) and intensifying flames (indicating proximity). However, they stressed that clear upfront explanations were still essential, as new visual metaphors could recreate earlier interpretation challenges without proper framing. This concern reflects DHH participants' heightened reliance on explicit visual meaning-making in the absence of auditory context. Their responses suggest that layered visuals can improve navigation, but only if the underlying metaphor is clear from the start rather than learned through trial and error.

***ii) Navigation Enhancements and Context-Sensitive Spatial Tools:*** All participants (11/11) appreciated the improved directional guidance, especially DHH users who had experienced prolonged disorientation in Phase 1. Most DHH participants (3/4) preferred glowing arrows over floating directional indicators. EP08 (HoH) explained:

> *"I feel like the second one [arrow above player's avatar] sort of defeats the point of hide-and-seek [...]. With the first one [glowing arrow], you would still have to kind of look for the sign."* [EP08, HoH]

This response shows that DHH participants evaluated directional guidance not only for clarity, but also for how well it supported visual navigation without overwhelming gameplay. Their preference for glowing arrows suggests a need for guidance that is visible and consistent while still supporting independent navigation without auditory cues.

Additionally, all DHH participants (4/4) supported minimaps for the "City (Free)" mode, where they had experienced the most challenges in Phase 1. Yet they advocated for context-sensitive rather than always-on implementation. EP08 (HoH) captured this tension:

> *"It's [minimap] a good addition, because I got lost in the mode [City(Free)] a couple of times. But having it always on kind of makes the search easy."* [EP08, HoH]

This reasoning echoes Theme 1's temporal accessibility insights: participants recognized that constant visual information could create cognitive overload in their primary sensory channel, similar to always-on captions in Phase 1. All participants (11/11) expressed interest in visual power-ups distributed across maps, which DHH participants viewed as exploration incentives driven by visual discovery rather than audio or narrative cues.

## 7 Discussion

### 7.1 Experience Grounded Participation and Design Reasoning

Consistent with prior work emphasizing lived, repeated use in design workshops and evaluation [87], our multi-phase approach shows how sustained engagement can deepen co-design. Unlike studies relying on short-term or single-session interaction [100, 118], Phase 1 involved multi-session use, allowing participants to move beyond first impressions and reflect on how the system intersected with their routines, bodies, and attention over time.

This extended exposure generated experiential knowledge unlikely to emerge through brief encounters. Participants reflected on recurring patterns rather than isolated challenges, explaining how specific interactions influenced their willingness to return. In this sense, Phase 1 functioned as a period of experiential grounding, providing concrete reference points that later shaped both design discussions and evaluative judgments.

Building on this foundation, Phase 2 workshops brought together participants with complementary expertise, including design students and returning Phase 1 participants [114]. Workshops were structured around the three DHH-specific accessibility themes identified earlier, ensuring that design conversations addressed documented challenges rather than hypothetical concerns. Returning participants brought lived experience from the 10-day study, while design students contributed technical perspectives. This shared experiential base supported collaboration despite differing interpretations. For example, a hearing participant might struggle with calibration, while a DHH participant also had to manage caption reading.

Phase 3 further revealed how prior use deepened evaluative reasoning. Rather than speculating abstractly, participants mapped design concepts onto previously encountered situations, using earlier experiences as evaluative anchors for judging whether proposed features would support sustained engagement. They also treated mockups as starting points rather than finalized solutions. For example, when reviewing SL video instructions, several participants suggested extending this approach to calibration through gesture-based trainer cues (e.g., "come closer" or "step back") instead of text. Participants further noted that accessibility solutions could introduce new tensions, as features such as always-on minimaps or persistent arrows might create visual overload with repeated use.

Additionally, in Phase 3, DHH participants guided discussions—identifying gaps, proposing alternatives, and articulating how accessibility should evolve over time [46, 114]. Their shift from describing experiences to directing design conversations shows how multi-session engagement fosters experiential grounding and design agency.

In summary, these phases show how sustained participation transforms co-design and evaluation from speculative exercises into experience-grounded, generative practices. By enabling lived use before design reflection and evaluation, our approach surfaces considerations often missed in single-session studies and offers a methodological pathway for examining how accessibility shapes motivation and engagement over time.

## 7.2 Temporal Dynamics of Accessibility Across Repeated Interactions

*7.2.1* ***Accessibility as an Evolving Design Requirement.*** Our findings show that accessibility requirements are not fixed but evolve as users gain familiarity and expertise through repeated MR exergame use. This invites reconsidering accessibility evaluation practices that often assess features in binary terms: working or not working, accessible or inaccessible [75, 104]. Our study shows that such evaluations can miss how accessibility features shift over time: mechanisms that support early access may later introduce friction as users' needs change [50, 54, 101].

In MR exergames, this evolution became apparent through repeated interaction. Features that initially supported orientation and learning became less effective as participants gained experience. Our findings suggest this shift reflects changes in how accessibility features interact with users' attention, bodily engagement, and developing competence.

For DHH participants, these changes were particularly salient because access relied almost entirely on visual channels [89]. Captions, onboarding instructions, and visual demonstrations were initially valued for supporting comprehension and confidence. As participants became familiar with the core mechanics, these features still required visual attention even though they were no longer as helpful. Over time, accessibility support began to compete with gameplay, spatial orientation, and physical movement rather than facilitating them.

Moreover, consistent with prior work [37, 76, 97, 120], our findings suggest that features designed for learning can become unnecessarily demanding as users gain expertise. These findings also highlight that accessibility evaluation based solely on initial effectiveness may be insufficient. Its role should be understood in relation to users' changing needs across repeated use.

*7.2.2* ***Accessibility, Motivation and Engagement as Interdependent Dimensions.*** From our findings, we observed that the shifts in accessibility had direct implications for motivation and engagement. In our study, accessibility features did not function as neutral infrastructure that simply enabled engagement. Instead, they shaped participants' willingness to return to the system. This pattern appeared in examples such as caption blocks, unskippable instructions, and static embodied interactions, where visual supports that initially aided understanding later competed for attention during movement-intensive activities.

These experiences suggest a close relationship between accessibility and engagement, which are often treated as separate design concerns [12, 104]. For DHH participants, accessibility features influenced not only whether interaction was possible, but also how effortful and appealing continued use felt. When accessibility support remained static, in several cases, it appeared to reduce motivation and engagement [12, 84], despite having been essential earlier.

In summary, our findings suggest that accessibility in systems intended for repeated use must evolve with users' growing expertise. Initial access is necessary but insufficient; accessibility features should adapt over time, balancing clarity with efficiency and support with autonomy. Designing for accessibility is therefore inseparable from designing for sustained motivation and engagement.

## 7.3 Design Directions and Open Questions

Building on DHH participants' responses to the Phase 3 design concepts, we present key design directions and open questions informed by participants' experiences across the study. We did not treat the proposed features as finalized solutions. Instead, participants reflected on how accessibility operates over time, how visual effort is managed, and how certain design choices can create new challenges or confusion. These insights point to design challenges that cannot be resolved through isolated features alone. Instead, they require careful consideration of adaptation, timing, and user agency. We therefore frame these observations as design directions accompanied by open research questions, highlighting areas where further investigation is needed to better support sustained motivation and engagement for DHH users in immersive exergaming contexts.

While prior work has examined aspects of motivation [111, 112], feedback [74, 86], accessibility [45, 72], and interaction design [31, 106] in games and XR systems, these questions are often studied in isolation or within short-term interactions. In contrast, our findings show how accessibility, visual attention, and interaction evolve together during DHH users' sustained engagement with immersive systems. Thus, the open questions we outline do not introduce entirely new problem spaces but reframe existing challenges through a longitudinal, accessibility-centered lens.

We note that Phases 2 and 3 translated and evaluated design concepts derived from Phase 1 rather than resolving these broader questions, which require extended deployments, adaptive systems, or controlled comparisons. Beyond exergaming, these directions may apply to various XR systems for DHH users in education, training, rehabilitation, and other contexts requiring sustained engagement.

#### *7.3.1* ***Managing Instructional Support: When and How Should Instructional Support Recede?***

Participants' responses to toggleable instructions in Phase 3, alongside Phase 1 observations of repeated instructional burden, reveal a temporal challenge: for DHH users, the issue is not instructional support itself, but how long it remains unchanged.

Accessibility mechanisms that are essential for early engagement can become effortful when they persist beyond their usefulness, yet removing them too abruptly risks undermining confidence and autonomy. This creates a control paradox. On one hand, granting users control over instructional intensity respects individual pacing and avoids premature withdrawal of support [6, 96]. On the other hand, asking users to decide when to reduce support assumes that self-assessment is easy, which can be difficult in practice [32, 94]. For DHH users, this assumption can be difficult, as accessibility features share the same visual channel as core interaction [48, 49], and deafness encompasses diverse experiences [67, 68].

Accordingly, future XR systems for DHH users should adapt instructional support based on user performance, gradually reducing visual density, adjusting placement, or shifting modality as users demonstrate mastery. These changes should remain visible and understandable so users retain a sense of control. However, this design direction leads us to a few open questions:

- How might systems signal transitions from learning to routine interaction without requiring DHH users to explicitly assess their own expertise?
- What indicators—behavioral, temporal, or interactional—could support adaptive shifts in guidance while preserving DHH users' sense of control?
- How can instructional support gradually recede in ways that remain legible and reassuring for DHH users who cannot rely on auditory feedback if visual information is reduced?

#### *7.3.2* ***Customization and Effort: When Does Flexibility Require Additional User Effort?***

Building on Phase 2 proposals and Phase 3 reflections, DHH participants viewed movable captions as a way to reduce spatial conflicts between reading and movement.

Yet, in this case, customization itself introduces work [29, 101, 121]. However, movable captions may require DHH users to decide where to place them and adjust them across activities. Participants imagined setting captions in a consistent location, suggesting that flexibility is useful only when it does not add setup effort.

Two complementary design directions emerge from these findings. First, XR systems could learn and restore caption positions based on activity context, such as standing exploration, seated crafting, or rapid movement, shifting configuration from a repeated task to a one-time contextual setup. Second, because caption challenges emerged at specific moments rather than continuously, caption prominence, including density, opacity, or update frequency, could adapt dynamically to real-time indicators such as movement velocity or visual scene complexity. Yet, several open questions become apparent:

- Should caption positioning be activity-aware, remembering preferred placements for different movement contexts? Or does this risk confusing DHH users when captions behave differently than expected?
- How can systems minimize configuration effort for DHH users while accommodating variability in body posture and activity type?
- What indicators should trigger temporal adaptations, and how should these changes be signaled to maintain predictability without audio cues?

#### *7.3.3* ***Designing Instructional Modalities: Does SL Solve What We Think It Solves?***

Phase 3 participants' strong preference for SL video instructions, building on Phase 2 mockups, suggests that text-based guidance can impose cognitive costs for users whose primary language is visual-spatial rather than written English.

This preference may reflect reduced linguistic translation, alignment with participants' primary communication modality, or the ability to process instructions while remaining physically engaged [71, 115]. However, SL videos may also introduce temporal challenges if users must repeatedly watch full demonstrations. In this scenario, the modality changes, but the demand for sustained visual attention remains. Thus, XR systems should treat SL instruction as phase-dependent: full demonstrations may support initial learning, while abbreviated gestural cues, key-frame reminders, or on-demand snippets may better support routine use.

These findings also inform AI-assisted accessibility in XR systems [25, 26, 78, 108, 109]. The need for SL instruction to evolve with user familiarity highlights the importance of temporally adaptive accessibility, where systems adjust instructional format, density, and timing based on users' changing competence [25, 108, 109]. Rather than providing static translation, AI-assisted accessibility should support dynamic, context-sensitive guidance that reduces attentional demands while preserving fast and accessible visual support. Still, several open questions persist:

- Is the value of SL instructions primarily linguistic, embodied, or attentional? Does this vary across DHH users' language backgrounds?
- How should SL instruction format evolve once activities are learned? What indicators should trigger transitions from full demonstrations to abbreviated cues?
- What forms of condensed SL reference (gestural symbols, key frames, partial replays) preserve accessibility while reducing temporal cost?

*7.3.4* ***Expressiveness in Feedback: When Does Feedback Start Competing for Attention?*** DHH participants' enthusiasm for expressive Peridot behaviours suggests that visual emotional feedback can serve communicative roles often carried by sound. Emojis and embodied reactions functioned as accessible emotional signals. However, participants evaluated these features through static mockups rather than active gameplay. Therefore, their potential benefits should be considered alongside Phase 1 findings that DHH users already navigate visually dense environments. Adding expressive animations could increase visual saturation, particularly during physically demanding activities [48, 83, 121].

These tensions suggest that expressive feedback in XR systems should function as a dynamic layer rather than a constant presence. Emotional signals, such as creature animations, emojis, or celebrations, could be amplified during lower-intensity moments. These include rest, exploration, or task completion, when DHH users may have greater visual capacity. During movement-intensive or visually dense gameplay, these signals could be reduced in prominence, frequency, or complexity to avoid competing with task-critical information. This approach preserves the motivational value of expressive feedback while respecting DHH users' visual bandwidth constraints. Nonetheless, these design directions introduce a set of critical open questions:

- What activity indicators should trigger adjustments in expressive feedback for DHH users? How should systems detect transitions between high- and low-intensity moments?
- Should expressiveness modulate gradually or shift between distinct modes? What forms of reduced expression (simplified animations, peripheral placement) preserve motivational value for DHH users?
- How do DHH users prioritise expressive feedback relative to functional visual demands during real-time activity?

*7.3.5* ***Instruction vs. Discovery: How to Balance Explicit Onboarding and Discovery-Based Learning?*** Phase 3 feedback on onboarding, alongside Phase 1 experiences of delayed understanding, highlights a tension between clarity and discovery-based learning, where unclear mechanics can become persistent barriers for DHH users.

Explicit onboarding was consistently valued, yet this raises tension with discovery-based learning. Hearing users may infer mechanics through audio cues [70], while DHH users lack these signals, making ambiguous mechanics harder to interpret and slower to resolve through interaction alone.

In this scenario, XR systems should not replace discovery with explicit instruction. Instead, they should make discovery-based learning structurally accessible for DHH users through a stronger visual design. This could include clearer affordances, contextual visual hints, and traceable feedback that makes cause-and-effect relationships immediately visible. Such support can reduce prolonged trial-and-error and remove reliance on incidental audio cues for DHH users. While promising, these directions require further consideration, raising several open questions:

- Which forms of visual guidance, such as enhanced affordances, progressive hints, or traceable feedback, best support discovery for DHH users without effectively becoming explicit instruction?
- Can improved visual design encourage DHH users to prefer exploration, or do past negative experiences with inaccessible discovery lead them to favor upfront certainty?
- How can systems balance the efficiency of explicit onboarding with the engagement and learning benefits of discovery-based mechanics?

In summary, our findings advance the field in three ways beyond DHH users and MR exergames. First, they reframe accessibility as a temporally evolving design requirement rather than a fixed property, with implications for repeated-use XR contexts such as rehabilitation, training, and education. Second, they position accessibility, motivation, and engagement as interdependent dimensions of player experience design. Third, they show that sustained, multi-session engagement before the design workshop can yield more ecologically valid insights than single-session methods. Although grounded in DHH users' experiences, these insights extend to contexts where visual accessibility features compete with immersive interaction for attention.

## 8 Limitations and Future Work

While our study offers valuable empirical insights, it has several limitations that should be considered when interpreting the findings. The DHH sample was small (6 participants in Phase 1, 1 in Phase 2, and 4 in Phase 3). This reflects the practical challenges of recruiting and retaining DHH participants for multi-phase studies that require access to suitable devices and sustained participation. While appropriate for exploratory qualitative research [70, 102], this limits generalizability.

Moreover, our findings represent insights from a specific group rather than patterns applicable to all DHH populations. The DHH community is heterogeneous, with varied hearing levels, communication preferences, and experiences, so findings may not transfer uniformly. Phase 2 included limited DHH participation, and as a result, several design concepts were developed mainly through the interpretations of game design students. This was partially mitigated in Phase 3, where DHH participants played a central role in evaluating and refining the proposed directions. In addition, although Phase 1 spanned 10 days, longer than typical single-session studies, it still represents a limited temporal window. As a result, we cannot determine how accessibility dynamics observed within days might unfold over longer periods of sustained use.

Additionally, the 10-day deployment captured early changes across repeated use, but not long-term habit formation or stable engagement patterns. In Phase 3, participants evaluated static mockups rather than functional prototypes, so their feedback reflected anticipated rather than experienced interaction. Although this approach supported concept-level reflection grounded in Phase 1 experiences, temporal accessibility dynamics require repeated use of working systems.

Accordingly, these design directions and open questions require further validation through longitudinal studies with functional prototypes. Our contribution is to surface these experience-grounded directions, while their impact on sustained engagement remains for future work. Finally, our study focused on a single MR exergame (*ARWell PRO*) in a home-based, individual-use context. Thus, findings may not generalise to exergame designs, multiplayer settings, or rehabilitation contexts with different motivational structures.

These limitations point toward necessary future research. Our future work will implement these design directions in MR exergames and evaluate how adaptive accessibility features shape sustained DHH engagement over 8–12 weeks. Through longer deployments, we aim to examine whether the accessibility needs and motivational patterns identified in this study persist, diminish, or transform over time. Moreover, future work could also include participants who did not take part in earlier phases to examine how prior exposure shapes feedback and to assess the generalizability of the proposed designs. Future work could also incorporate repeated standardized measures, such as usability or ease-of-use scales, with larger, more diverse samples to complement qualitative findings and systematically examine changes over time.

Furthermore, comparative studies could examine how temporal accessibility dynamics differ across DHH subgroups (ASL vs. oral communication, varying hearing levels), exergame designs (different caption systems and instruction modalities), and contexts (recreational vs. therapeutic use). In addition, future methodological work should explore how to sustain DHH participation in extended co-design, including flexible engagement formats. Beyond DHH populations, cross-disability research could examine whether similar temporal accessibility dynamics emerge among users who rely on other sensory or cognitive channels. Finally, theoretical work conceptualizing accessibility as an adaptive process responsive to growing expertise and changing demands could extend these insights toward immersive systems that evolve with users.

## 9 Conclusion

This work examines how DHH users experience motivation and engagement in MR exergames across repeated sessions, addressing an underexplored aspect of accessibility research: how accessibility needs change as users gain familiarity over time. Through a three-phase exploratory study combining repeated use over 10 days, the design workshop, and feedback on visual mockups, we show that accessibility is not a static property but a temporal relationship that changes with users' familiarity and expertise. Features that supported initial access, such as captions, visual instructions, and onboarding, became more effortful as they competed with gameplay for visual attention. This created cumulative cognitive demands for DHH users, who often cannot shift information load to auditory channels. Our multi-phase approach revealed dynamics that single-session evaluations often miss. These include how accessibility features change over time, how repeated engagement develops design insight, and how static support can undermine long-term motivation. Based on these findings, we propose design directions for temporal accessibility, including adaptive instruction, customizable visuals, multimodal guidance, expressive feedback, and context-sensitive cues. We also highlight open questions about control, effort, modality, and visual load. At the same time, the study's scale, duration, and use of conceptual mockups highlight the need for longer-term validation with functional systems and broader DHH participation. Future work should examine how adaptive accessibility features perform over time and in different contexts and develop design frameworks that support changing user needs and expertise. Although grounded in MR exergaming, these insights may extend to other immersive systems that require sustained engagement, such as rehabilitation, education, and assistive technologies.

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## A Details of the Activities In The Game

Table 6. Details of Activities

| Activity Name | Activity Details | Modes | Mode Details |
|---|---|---|---|
| *Hide and Seek* | Players are required to position their device at a distance that enables full-body capture, ensuring the system can track movements from head to toe (Figure 1). An on-screen avatar represents the player, and physical movements are mapped onto the avatar's actions. For instance, marching in place translates to forward movement, while head turns alter the avatar's directional orientation. The primary objective of the activity is to locate the trainer before the virtual character Peridot does. A "hot and cold" visual meter is displayed on screen to indicate the player's proximity to the trainer, providing continuous spatial feedback throughout the task. | Stadium | This mode is set within a relatively smaller virtual space compared to the other activities. It takes place in a stadium setting (Figure 2a) that includes a limited number of objects serving as obstacles within the space. |
| | | City (Guided) | This mode is set in a virtual city environment (Figure 2b), where surrounding buildings serve as obstacles throughout the map. Wooden arrows are strategically placed across the city to guide the player toward the trainer's location. |
| | | City (Free) | This mode also takes place in a virtual city environment and shares structural similarities with the "City (Guided)" mode. However, unlike the guided version, this mode does not provide directional assistance, requiring the player to navigate independently (Figure 2c). |
| *Mini Squats* | Similar to the *Hide and Seek* activity, players are required to position their device at a distance sufficient for capturing their full-body movements from head to toe. Players select the number of squats they wish to perform in a session. Both the trainer and the virtual character Peridot appear on the screen, with the trainer providing real-time guidance on proper squat technique. The session concludes once the player completes the predetermined number of squats. | 1 | Peridot appears in the lower-left corner of the screen and displays various animated reactions throughout the activity (Figure 3a). |
| | | 2 | A progress bar is displayed on the left side of the screen, where Peridot progressively jumps upward as the player completes more squats (Figure 3b). |
| | | 3 | As the player performs squats, Peridot appears to jump onto the player's shoulder, providing a playful visual response to their movements (Figure 3c). |
| *Run In Place* | As with the other two activities, players must position their device at a distance that allows for full-body capture. In this task, players are instructed to run in place for one minute at a pace of their choosing. Both the trainer and the virtual character Peridot are present on the screen, with the trainer offering real-time guidance on running posture and movement. | 1 | Similar to the mode one of *Mini Squats* activity, Peridot appears in the lower-left corner of the screen and performs various animated reactions in response to the player's actions (Figure 4a). |
| | | 2 | Similar to the mode two of *Mini Squats* activity, a progress bar is displayed on the left side of the screen, where Peridot jumps higher along the bar as the player's running speed increases (Figure 4b). |
| | | 3 | Similar to the *Mini Squats* activity, as the player runs in place, Peridot appears to jump onto the player's shoulder, providing a dynamic visual response to their movement (Figure 4c). |

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