Motivation and Re-engagement in Mixed Reality: How Deaf and Hard of Hearing Users Experience a Mixed Reality Exergame

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ABSTRACT

As mixed reality (MR) technologies become increasingly prevalent in entertainment, particularly in gaming, it is crucial to understand how users with diverse communication needs engage with these environments. However, little is known about the motivational experiences of Deaf and Hard of Hearing (DHH) players in MR games. Our study investigates the factors that influence motivation and re-engagement among DHH participants using a ten-day deployment of an MR exergame. Six DHH participants with varying hearing status completed daily gameplay sessions and surveys for ten consecutive days, followed by in-depth interviews. We identified key barriers to sustained engagement, including challenges with closed captions (CCs), insufficient instructional clarity, and the absence of dynamic visual cues. Based on participant feedback, we offer design recommendations for improving accessibility and supporting long-term motivation in MR environments, such as customizable CCs, sign language alternatives, and real-time visual guidance. These findings contribute to a deeper understanding of inclusive design for DHH users in MR gaming contexts.

CCS CONCEPTS

• **Human-centered computing** → **Accesibility**; **Mixed Reality**.

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1 INTRODUCTION

Mixed reality (MR) has rapidly expanded across various domains, including education [19, 23], training [17], collaboration [26], healthcare [12], and entertainment [8]. Among these, MR has gained notable popularity in the entertainment industry, particularly in gaming [14, 16]. As MR games become increasingly immersive and interactive, it is essential to understand the factors that influence player motivation and engagement [27]. However, prior research provides limited insight into how these factors operate for players from marginalized groups, such as Deaf and Hard of Hearing (DHH) people, whose experiences in MR environments are often shaped by distinct sensory and communicative needs [13, 32].

Prior research in accessibility and MR has predominantly focused on the development and evaluation of assistive technologies or interface adaptations [5, 10, 29]. While these efforts are significant, there remains a lack of empirical investigation into how DHH players experience motivation in MR gameplay and what design elements either support or hinder their desire to return to the game. The absence of such understanding restricts the potential for creating more inclusive and sustainable MR game environments that actively support diverse user groups.

Building on prior work in MR exergames and accessibility, our study examines motivational factors that influence DHH players' gameplay and re-engagement. Using a prototype of *ARWell Pro* [1] as a research probe [3], we recruited six DHH participants with varying hearing abilities. Participants engaged in remote gameplay across ten consecutive days in their preferred environments. The game included three activities: hide-and-seek, mini squats, and run in place, which were completed daily, followed by survey responses and a post-study interview.

Our work presents early findings on how MR design decisions impact the motivation of DHH players. Notably, participants valued the presence of closed captions (CCs), yet encountered challenges such as difficulty reading from a distance, obstruction of game visuals, and insufficient or unclear text-based instructions. These findings emphasize the need for more accessible MR design through customizable sign language (SL) instructions, adaptable CCs, and clear visual cues that minimize reading demands.

2 BACKGROUND

2.1 Exergames in MR

MR exergames represent a promising approach to promoting physical activity, especially for people with targeted health or rehabilitation needs. For instance, MR-based exergames have been developed to support endurance and strength training in older adults, demonstrating high levels of enjoyment, usability, and motivational potential when integrated with immersive platforms and gamified mechanics [2, 5, 29]. In clinical rehabilitation contexts, MR exergames have been employed to enhance upper limb function and postural control through tangible interactions and robotic assistance, highlighting their effectiveness in stimulating task-specific movements and real-time performance tracking [10, 11].

2.2 Accessible Designs in Digital Games for DHH Players

Prior research in accessible game design has made significant progress in addressing the needs of DHH players, particularly within educational and inclusive contexts. For example, the GIM project was developed to promote inclusive education through hands-on interaction and visually rich content tailored for DHH learners [6]. Westin et al. [7] introduced preliminary design guidelines that emphasize the integration of sign language (SL) as a core design element, advancing the linguistic accessibility of digital games. Similarly, Di Mascio et al. [25] proposed a comprehensive set of design recommendations grounded in empirical and cognitive insights from DHH users, focusing on text presentation, interface interaction, and feedback strategies.

2.3 MR for DHH Users

Several studies have highlighted the technical feasibility and accessibility of MR in collaborative and learning settings. For instance, Waldow and Fuhrmann [32] developed MASR, an MR-based speech recognition system that displays floating captions near speaker avatars. Similarly, visual cues in MR, such as glow, pointing, and light indicators, have been shown to support speaker identification [13] and enhance sign retention and emotional engagement in SL learning [15]. In related work, MR systems effectively signaled key concepts and guided attention [22], while visual interactivity, avatars, and simplified interfaces supported sign acquisition and engagement [18].

While Section 2.1 highlights the potential of MR exergames for promoting physical activity and supporting specific rehabilitation needs, and Section 2.2 and 2.3 highlight usability and accessibility benefits for DHH users, both overlook how these features influence intrinsic motivation and long-term engagement, factors essential for sustained use.

3 METHOD

Our study was conducted in two phases: (i) a ten-day gameplay session involving three MR activities from the *ARWell Pro* application, followed by a daily survey after each session, and (ii) a semi-structured interview conducted upon completion of the gameplay period. *ARWell Pro* is a guided MR exercise application designed to run on tablets, laptops, and smartphones, with an emphasis on large-screen usage (greater than 10 inches) to ensure full-body visibility during gameplay. The application requires users to position themselves approximately eight feet away from the screen to allow the system to capture their body movement accurately (Figure 1 in Appendix A). Participants were also given the option to connect their device to an external monitor to enhance visual accessibility.

Through a research partnership with *ARWell Pro*, we accessed three prototype activities in development at the time of the study. Each involved two virtual entities: a trainer who provided verbal instructions with CC, and Peridot, a character acting as a companion or competitor depending on the activity. The activities included (i) Hide and Seek, an exploration task where players search for a trainer character (Figure 2 in Appendix A); (ii) Mini Squats, a guided squat exercise with user-defined repetitions (Figure 3 in Appendix A); and (iii) Run in Place, a one-minute stationary running task performed at the participant's preferred pace (Figure 4 in Appendix A). These activities were only compatible with a limited range of devices, specifically, newer-generation iPads, iPad Pros, iPad Airs, and MacBooks with M1 chips, due to the technical requirements of the prototype software at the time of the study.

3.1 Participants

Participants were recruited via flyers at a local college, email outreach, and social media posts targeting Deaf community groups. An online registration form collected demographic data, hearing status, pronoun preference, access to compatible devices, and willingness to complete ten days of physical activity. Participants reported using either an iPad (8th or 9th generation, Air 4th generation, or Pro models) or a MacBook with an M1 chip, and each participant used the same device consistently throughout the study to ensure stable performance and to capture accuracy. Six self-identified DHH participants aged 22 to 59 were enrolled, including four Deaf and two hard-of-hearing individuals. Three preferred ASL, and three preferred spoken English.

3.2 Procedure

Following recruitment, each participant was sent an informed consent form outlining their rights and the study's expectations. Participants were notified that participation was voluntary and that compensation would be provided only upon completion of all ten gameplay sessions and associated surveys. Upon receipt of consent, 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 ten consecutive days from 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. Upon completing the ten-day gameplay period, participants were invited to a remote, semi-structured interview conducted via video conferencing. Interpreters were made available for participants who preferred 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 electronic gift card as compensation upon completing both the gameplay and interview phases of the study.

3.3 Data Analysis

To support our study design, we monitored participants' gameplay over ten days to ensure task completion and reduce discrepancies between behavior and survey responses. Daily surveys served as reflective diaries, informing the development of interview questions. Semi-structured interviews were the primary qualitative data source. We verified the transcripts against audio recordings, then analyzed them alongside survey data using MAXQDA [31]. We conducted reflexive thematic analysis (RTA) [4] with inductive coding [30], employing both semantic and latent approaches to identify themes related to motivation and interaction challenges, which informed the findings.

4 FINDINGS

From qualitative data from daily surveys and post-gameplay interviews, we identified recurring challenges and motivational barriers experienced by DHH participants. We identified two primary themes: (i) caption visibility and spatial tension, and (ii) limitations of instructional content and visual guidance.

4.1 Caption Visibility and Spatial Tension

All participants (6/6) relied on CCs for accessing instructional content, including those with some residual hearing (3/6). While captions were intended to increase accessibility, their presentation created notable conflicts between visibility and gameplay interaction. Specifically, participants were required to stand at least eight feet away from the screen for the application to recognize their full-body motion. However, the caption size and screen placement often made reading difficult from that distance, prompting participants to move forward to read instructions and then return to the detection range of the system. Notably, all participants used either iPads or MacBooks for their gameplay, without connecting to external monitors. Additionally, none of the participants reported any vision-related issues that would prevent them from reading closed captions from a distance of eight feet. P01 described this back-and-forth motion,

> "I had to move forward to read the closed captions properly, but when I do so, the app tells me to back away." [P01, HoH]

Similarly, P04 expressed a desire for captions to remain legible without requiring constant movement,

> "I want to be able to read the captions as the actions are happening on the screen, and for that, I had to move back and forth quite a few times." [P04, Deaf]

In addition to spatial challenges, participants noted that the caption placement often occluded key gameplay elements. Three participants (3/6) specifically referenced this issue during the "hide and seek" activity, where caption blocks interfered with visual tracking of in-game objects. P05 stated,

> "I noticed the closed captions were on the screen in big chunks, and sometimes they were stuck, like two long lines at once, and I felt it was blocking me from viewing the whole screen [...]. It was kind of getting annoying, especially for the last five days." [P05, Deaf]

These issues persisted throughout the ten-day period and became more pronounced during the latter half of the gameplay, negatively impacting participants' motivation and diminishing their desire to continue or revisit the game. The findings highlight a need for adaptive captioning strategies that account for player distance, visual load, and unobstructed spatial awareness.

4.2 Limitations of Instructional Content and Visual Guidance

Participants unanimously (6/6) appreciated the availability of text-based instructions; however, a majority (4/6) indicated that the instructions were either insufficient or overly complex in specific segments of the game. These issues were most prominent during the setup and calibration phases. P03 shared confusion regarding the spatial positioning instructions,

> "There was an image about telling me where I need to place my device and where I should stand [...]. But it took me a couple of times to get it." [P03, Deaf]

P02 noted the interface's cognitive load when multiple elements were presented simultaneously,

> "It felt like way too much going on at the same time, with the image and the calibration all on the same screen [...]. I would prefer dividing them [visuals for instructions and calibration] into separate screens." [P02, Hard of Hearing]

Furthermore, participants (3/6) emphasized the absence of dynamic visual cues to supplement or clarify text-based instructions. Instead of relying solely on static indicators, they suggested incorporating real-time directional or action-based prompts. P06 explained,

> "In the calibration screen, there were only top and bottom circles [...]. In the beginning, I did not understand if I should go backward or forward [...]. I am hoping in later versions of the game this will be improved." [P06, Deaf]

The lack of dynamic, intuitive instruction delivery not only led to confusion but also contributed to a decline in gameplay engagement. Participants expressed that these moments disrupted their immersion and reduced their motivation to return to the game.

5 DISCUSSION AND LIMITATIONS

CCs are commonly used to convey audio-based instructions in augmented [28] and virtual [33] reality, and have shown similar utility in MR; however, their use in the MR exergame introduced usability challenges. Participants had to stand over eight feet from the screen for full-body capture; however, bottom-anchored captions caused visibility and readability issues. These limitations compelled players to move repeatedly toward and away from the screen, which disrupted their engagement and diminished motivation over time. To address these challenges, future MR systems should support customizable caption features, including adjustable font size, text

segmentation, and repositionable caption overlays that do not interfere with essential game visuals. In addition, offering an alternative mode of instruction, such as SL interpretation embedded within the interface [7], may provide a more direct and inclusive communication channel, especially for users who rely primarily on visual-spatial language.

Participants generally appreciated the presence of text-based instructions [21] but indicated that still images and static prompts were often insufficient for conveying spatial tasks. Ambiguities in the setup and calibration stages highlighted the need for more intuitive and dynamic guidance. Participants expressed a preference for multimodal cues [13, 18], such as animations or real-time visual markers that correspond to body position or task progress. These findings suggest that instruction systems in MR environments must account for perceptual load and minimize cognitive fragmentation [25]. Concise, sequential, and context-aware visual cues can enhance clarity, immersion, and sustained motivation in MR [9, 20], particularly for users who depend on non-auditory information.

While the study contributes meaningful insights, it is not without limitations. The participant sample was relatively small (N = 6), which may limit the generalizability of the findings. However, this sample size is consistent with prior research involving DHH users and aligns with qualitative inquiry practices in accessibility studies [24]. Additionally, we conducted the study using a single MR exergame prototype on a limited range of compatible Apple devices, which may influence its ecological validity and limit the extent to which the findings generalize to real-world use across other platforms. Future research should involve a more diverse participant pool, representing a wider range of demographics and communication preferences, to strengthen the validity and applicability of the findings. Additionally, replicating the study with multiple MR exergames on various devices and operating systems would allow for comparative analysis of user experiences and motivational factors across different contexts. Additionally, the study focused exclusively on a gamified MR application designed for guided physical activity. Other MR applications, such as educational or productivity tools, may introduce different motivational or accessibility dynamics. Comparing experiences across varied application domains could help uncover both universal and context-specific design implications.

6 CONCLUSION AND FUTURE WORK

Our study explored the factors that influence motivation and reengagement among DHH participants in an MR exergame. Through a ten-day study, we identified key challenges related to caption accessibility, instruction clarity, and visual guidance. Although participants valued CCs and text-based instructions, spatial constraints and limited visual cues hindered gameplay and reduced long-term motivation. The findings underscore the importance of designing MR experiences that account for the physical positioning, perceptual preferences, and communication modalities of DHH users. Customizable CCs, SL instructions, and dynamic visual cues present promising strategies for enhancing accessibility and engagement in MR environments. In future work, we aim to translate these recommendations into interactive prototypes that directly reflect participant feedback. By returning to the same participant group to validate these designs, we seek to empirically assess which design strategies enhance motivation and encourage repeated engagement. This iterative, user-centered approach will deepen our understanding of inclusive MR design and inform the development of more accessible and motivating MR experiences for DHH users.

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A DETAILS OF THE ACTIVITIES IN THE GAME

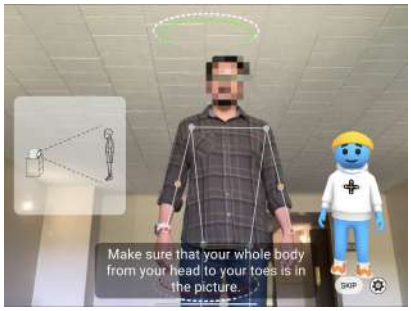

Figure 1: Calibration screen before each of the activities.

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

Figure 2: Three modes of Hide and Seek.

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

Figure 3: Three modes of Mini Squats.

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

Figure 4: Three modes of Run In Place.