MIRAGE: Mixed Reality Alerts for Guarding Against Environmental Fall Hazards

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Figure 1: Mixed Reality devices could potentially warn its users about fall hazards such as staircases. In our explorative prototype study, participants tested three different warning types: A superimposed small line at the stair landing (*Left*), a bigger warning including a text label (*Middle*), and a full-scale warning blocking the whole stair entrance including a text label (*Right*).

Abstract

This study investigates the effectiveness of Mixed Reality (MR) warnings for fall hazards, focusing on user perception and the impact of warning size, color, and visual complexity. Using a commercial off-the-shelf MR device, three different warning sizes were displayed in front of a staircase, and data were collected from twelve participants through semi-structured interviews. Findings revealed that while larger warnings attracted more attention, they sometimes became distractions instead. Participants preferred conspicuous colors and medium-to-large warnings but noted the need for these elements to blend seamlessly into the real-world environment to avoid cognitive overload. Additionally, participants expressed a desire for MR warnings in more safety-critical environments, such as road traffic scenarios. These results highlight the need for a balanced approach to MR warning design, ensuring they are noticeable without being intrusive to enhance safety in dynamic environments.

CCS Concepts

• **Human-centered computing** → **Mixed / augmented reality**; **Interaction techniques**; **Accessibility technologies**.

Keywords

Mixed Reality, Hazards, Warnings

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1 Introduction and Background

As Mixed Reality (MR) technology becomes increasingly integrated into daily life, optimizing its benefits while prioritizing user safety is deciding. The immersive nature of MR, where virtual elements blend with the physical environment, poses unique challenges, particularly in effectively communicating information in users' multi-layered contextual surroundings. These challenges are particularly pressing in environments where users may be exposed to physical hazards, such as stairs, which are ubiquitous sources of potential falls. Previous research already discussed physical safety challenges that MR may bring [4, 7], which include but are not limited to immersive attacks that focus on manipulating users' perceptions rather than targeting traditional hardware or software vulnerabilities [1, 3, 16] and the safety and health concerns of MR applications. For the latter, distractions play an especially large role [5]. Furthermore, accidents have been reported both in scientific [11, 13] and media publications[1,2] where MR applications played a factor in users getting injured. Previous related work already looked at the use of MR for crash avoidance in various safety-critical environments [6, 8, 9, 15], underscoring the need for and current relevance of adequate safety measures in MR environments.

Therefore, our work investigates the perceived effectiveness and users' preferences of MR warnings in a real-world environment, focusing on their ability to alert users to environmental fall hazards like stairs.

2 User Study

The warning design follows the principles of Laughery et al. [10], which include the strategic placement of warnings close to the object of caution to prevent oversight. These warnings include the signal word "Attention!" to heighten awareness and use the color orange as a noticeable color without evoking the imminent urgency of a warning associated with red. The warnings were designed to allow participants to locate them swiftly, as longer text would take more time to process [2]. We created three warning signs with different prominence levels and displayed each at stair landings to draw attention to the stairs and prevent accidents. The three types of warnings are shown in Figure 1.

We used a Microsoft HoloLens 2[3] to display the warnings. Since this study focuses on the design and qualitative assessment of participants' perceptions of the size and noticeability of the warnings rather than developing a fully functional system, we chose to use QR code detection instead of detecting staircases through the device's camera visual stream. The study employed a counterbalanced within-subjects design, where the participants were instructed to walk down a roughly 100-meter-long hallway in an office environment past three staircases of the same design. Therefore, each participant walked down this hallway three times, once for each warning design. We printed and put Vuforia markers[4] next to each of the staircases and positioned the warnings in relation to this QR code for reasons above. Semi-structured interviews were conducted and recorded after all three warnings had been tested to explore the participant's observations, insights, preferred MR warning types, and considerations for other environments. At least one of the researchers was always present throughout the study to protect the participant from potential injuries. We recruited twelve participants (eight self-identified as female, four self-identified as male) aged 21 to 67 ($\bar{x} = 34, s = 15.95$).

[1]https://www.washingtonpost.com/news/the-switch/wp/2016/07/08/pokemon-gos-unexpected-side-effect-injuries/, last accessed on 2024-10-17.
[2]https://www.sandiegouniontribune.com/2016/07/14/pokemon-go-players-fall-off-90-foot-ocean-bluff/, last accessed on 2024-10-17.
[3]https://www.microsoft.com/en-us/hololens, last accessed on 2024-10-17.
[4]https://developer.vuforia.com/library/objects/image-targets, last accessed on 2024-10-17.

2.1 Results

We conducted qualitative interviews with our participants to assess the preferred designs for hazard warnings. One researcher transcribed the data verbatim. Then, the researcher coded and clustered the semantics of the statements. Regarding the semantics of the participants' answers, we identified the clusters of **warning identification**, **warning size**, **changes in real-world connection**, **enhancement suggestions**, and **concerns related to higher risk scenarios**. Two-thirds of participants reported no active discomfort with the three warnings, though some expressed minor concerns about visibility. All participants could see the three distinct designs of warning signs that were presented and generally agreed that warnings like these could be integrated into everyday MR usage. However, concerns arose regarding the **visibility** and **size** of such warnings, with some fearing they might be too inconspicuous to notice. Eight participants found the small safety warning inadequate. They felt it was too **inconspicuous and easily overlooked**. In contrast, four participants explicitly preferred the large warning; two others found it still effective. They appreciated the large warning's **size and visibility**, ensuring it was easily noticed and quickly perceived, especially since it was within the field of vision rather than on the ground like the small warning. Six individuals mentioned being bothered by the large warning, restricted from further movement, distracted by its size, or occasionally startled. The medium warning was seen as a balanced option, as its **size** was seen as proportionate to the source of danger, such as stairs, providing a sense of caution without hindering movement. Several participants agreed on the importance of these warnings in MR, mentioning it can lead to a tendency to **forget about real-world dangers**, as virtual elements overlay the physical environment, potentially diverting attention away from actual hazards.

2.2 Discussion, Limitations, and Future Work

The analysis of the qualitative data presented in the previous section allows us to discuss the implications of developing MR environments related to dangers and hazards in everyday environments. In addition to well-established observations, such as larger warnings attracting more attention and a general interest in a system capable of warning users about potential hazards, the following part presents more nuanced findings. Our interviews revealed that participants sometimes felt distracted when viewing MR warnings during the study, a common phenomenon when users do not expect visual intervention in MR [12]. When assessing the effectiveness of MR warning signs, creating an environment that minimizes distractions is essential. Since the warnings are designed to ensure that users notice potential hazards even when distracted by MR content, the warning itself becoming a distraction is a critical system failure.

The warning signs were the only visual MR element. However, MR elements could lead to even more distraction in scenarios with more visual elements. Regarding design choices for MR warning signs [14], choosing more noticeable colors than those typically used for physical warning signs is recommended while still adhering to general design principles as the presentation of warnings differs from physical signs, and participants needed time to register these MR warnings as such. Again, this raises the need to design MR warnings that are noticeable enough to be effective while not too distracting. The color and complexity of the design allow for ample adjustments to reach this goal.

We acknowledge that our study is prone to limitations. Our study was conducted in an enclosed indoor space, which may not fully replicate real-world conditions. A major limitation of this study is also the small sample size of 12 participants, which allows only some first insights into the perceived effectiveness of such a system. Future research should explore the effectiveness of MR warning signs in diverse real-world environments and investigate other forms of warning modalities, such as audio warnings or vibrotactile feedback. Additionally, studies should examine how users adapt to MR warning systems over an extended period.

3 Conclusion

The study shows insights into the design and effectiveness of MR warnings for potential hazards. While MR technology offers promising solutions for enhancing safety in environments with fall risks and other dangers, our findings reveal significant challenges that must be addressed. The counterintuitive effect of MR warnings becoming distractions shows fundamental issues for MR warnings. This distraction can undermine the very purpose of these warnings, suggesting that more careful integration of MR elements into the physical environment is necessary to avoid cognitive overload and ensure a non-distractive user experience. Finally, the study shows the importance of subtle MR warning designs, where effectiveness, user perception, and environmental integration are carefully balanced to maximize safety and minimize unintended consequences.

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