

Evaluating the Effects of a Virtual Reality Serious Game on Flood Risk Awareness

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Figure 1: We evaluated a VR-based serious game for flood management using a virtual tabletop environment.

Abstract

Urban flooding is an increasing challenge for cities, making public awareness of flood-related risks an important factor for response. This study investigates a virtual reality (VR) serious game that places users in a strategic role during the response phase of an urban flood scenario. The game combines an immersive VR environment with time-critical decision-making on a three-dimensional (3D) city map to support experiential engagement with flood management. We conducted a pretest-posttest study ($N = 23$). Flood risk awareness and perception were measured before and after the VR experience, while user experience and perceived workload were assessed post-intervention. Results show a significant increase

in flood risk awareness and risk perception following gameplay. User experience results show differentiated evaluations across dimensions, while workload measures reflect low mental demand alongside higher temporal and effort-related demands. The findings suggest that VR serious games focusing on response-oriented decision-making can effectively support flood-related awareness.

CCS Concepts

• Human-centered computing → Empirical studies in HCI; Human computer interaction (HCI).

Keywords

virtual reality, games, serious games, flood, flood risk awareness, flood risk perception



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1 Introduction and Motivation

Natural disasters, such as floods, can have detrimental effects on people and goods [4, 10]. At the same time, climate change will actually increase the risk of flood disasters, as sea levels rise and storm surges and heavy rainfall become more frequent [8]. An important factor in encouraging citizens to take precautions to prepare themselves is raising awareness of the risks and dangers of flooding [1]. Although previous research shows that knowledge is linked to awareness [9], imparting knowledge alone does not necessarily lead to increased risk awareness [19]. Another important factor is experience, as people who have already been affected by flooding show greater awareness afterward [1, 3]. Besides real experiences, serious games have the potential to let people experience flood situations, yet without facing real-world dangers [6]. For instance, several games have been developed that let players take on the role of a flood policy strategist with the task of increasing flood mitigation measures, such as building up flood defense [2, 5, 15]. Further, virtual reality (VR) has the potential to immerse players in simulated flood situations by allowing them to experience a flood from a first-person perspective, e.g., by observing the rising water levels around them [12, 18]. While these approaches highlight the potential of serious games and immersive VR experiences, previous works typically differ in the roles assigned to players and the phases of flood management they addressed. In Mol et al. [12]’s serious game, players take on the role of a citizen, focusing on individual protective actions during a flooding event. Similarly, the non-VR games often present the role of decision-makers, to emphasize planning and preparing, such as implementing protective measures and assessing long-term risk reduction strategies [2, 5, 15]. While these aspects of flood scenarios are important, we focus on the response phase, which involves time-critical actions aimed at protecting lives and property [16] during the flood event, to offer a different perspective. Accordingly, we design a VR game that combines the immersive aspect of VR with strategic, time-critical flood management tasks. In the game, the player’s task is to react to danger by employing available units, such as police and firefighters, while constantly facing a scarcity of resources and time pressure, aiming to convey the difficulty and seriousness of such situations. Using this game, we ask the following research questions:

- **RQ1:** How does our strategic VR game influence flood risk awareness?
- **RQ2:** How are the user experience and workload of our strategic VR game perceived?

To answer these research questions, we conducted a pre-post design user study. Our findings show that the game improved participants’ flood risk awareness. We found that user experience evaluations varied across dimensions, while workload measures suggested low mental demand with higher demands related to time pressure and continuous interaction. We discuss potential explanations of the results and provide recommendations for future work.

2 User Study

To investigate the effects of a VR serious game on flood risk awareness, perceived workload, and user experience, we conducted a user study with ($N = 23$) participants.

VR Game. This game focuses on managing a flood simulation in the city of Hamburg. It is set in a virtual conference room, where a table-mounted 3D map of the city serves as the main interaction area. The application was developed using the Unity game engine, integrates real-world geospatial data via the Cesium platform¹, and was deployed on a Meta Quest 3 head-mounted display.

Participants completed a five-minute flood management task in which they were tasked to minimize damage in a simulated urban flooding scenario. As the task progressed, water levels continued to rise and began to affect buildings across the city map. Participants could respond by evacuating buildings, securing basements, placing sandbags, and handling emerging emergencies. All actions were constrained by limited resources, including the availability of fire department units, police forces, and sandbags, requiring participants to manage their decisions within the given time frame. Interaction with the system was carried out using VR controllers. Before the main task, participants completed a short tutorial to familiarize themselves with the game mechanics and controls.

Methodology. The study followed a pretest-posttest design with a single condition to examine changes in awareness resulting from the VR serious game. Flood risk awareness was measured using the Flash Flood Risk Perception Questionnaire (FFRPQ) [14], using its awareness and risk perception sections, and excluding the preparedness section, as that is more about “people’s actions and readiness for floods” [14], which our serious game does not address. Perceived workload and user experience were measured after the VR experience using the NASA Task Load Index (NASA-TLX), which has six dimensions (e.g., mental demand) [7] and the User Experience Questionnaire (UEQ), with six dimensions (e.g., Attractiveness) [11], respectively.

Participants. Twenty-three participants (16 men, 7 women), aged between 19 and 43 years ($M_{age} = 24$, $SD_{age} = 5.47$), took part in the study. Most participants lived in urban areas, and the majority resided in Hamburg (20 out of 23). Participants reported varying levels of prior experience with VR: no prior experience ($n = 6$), tried VR once or twice ($n = 12$), occasional use (about once per month, $n = 1$), and regular use (weekly or more often, $n = 4$).

Procedure. In the study, upon providing informed consent, participants completed a demographic questionnaire and the pretest questionnaires. They then interacted with the VR serious game. Following the gameplay, participants completed the posttest questionnaire as well as the NASA-TLX and UEQ.

3 Results

To analyze the data, first, we checked the normality by the Shapiro-Wilk test. Due to normality violation, we performed Wilcoxon signed-rank tests.

For the NASA-TLX and the UEQ ratings, which were measured only after the VR gameplay, we list the descriptive statistics (see

¹<https://cesium.com/>

Table 1: Descriptive statistics (mean and standard deviation) for post-only questionnaires (NASA-TLX, UEQ).

NASA-TLX	Mental	Physical	Temporal	Performance	Effort	Frustration
Mean (SD)	11.6 (10.8)	46.9 (22.2)	60.9 (30.5)	49.8 (31.2)	49.3 (19.2)	42.5 (25.4)
UEQ	Attractiveness	Perspicuity	Efficiency	Dependability	Stimulation	Originality
Mean (SD)	0.71 (0.72)	1.14 (0.57)	1.43 (0.51)	0.81 (0.68)	1.33 (0.91)	0.86 (0.79)

Table 1). We found a significant increase in both FFRPQ awareness (Pre: $Mean = 3.13$, $SD = 0.63$; Post: $Mean = 3.61$, $SD = 0.72$; $W = 4$, $p = .015$, $r = .53$) and risk perception (Pre: $Mean = 3.04$, $SD = 0.56$; Post: $Mean = 3.74$, $SD = 0.62$; $W = 0$, $p < .001$, $r = .77$) from the pre- to the post-measurement.

4 Discussion and Conclusion

Our findings suggest that the VR serious game, where participants could experience a simulated flood scenario virtually, increases their awareness of flood risks. This supports prior work indicating that experience plays an important role in shaping flood risk awareness and perception [1, 3], and that besides real-life flood experiences, playing games also has this effect [2, 12].

While previous research has shown that VR simulations of floods can increase flood risk perception [13], which is defined as “people’s feelings, concerns, and beliefs about flood” [14], our results extended their findings and indicate that such experiences may also support broader aspects of flood-related awareness, regarding decision-making during an unfolding flood situation.

The experienced workload provides additional context for the findings. Participants reported low mental demand, suggesting that the task was easy to understand. In contrast, higher temporal, effort, and physical demands reflected the intended time pressure and continuous interaction required by the scenario. This suggests that perceived workload was mainly driven by the simulated flood response itself rather than by usability or comprehension issues.

Among the UEQ dimensions, attractiveness received a comparatively lower mean score. Given that most participants were from Hamburg and encountered their own city as the affected flood location in the game, this lower attractiveness score may reflect the emotionally challenging nature of engaging with a disaster scenario in a familiar real-world context. In contrast, stimulation showed the highest mean score, falling within the good range according to the UEQ benchmark [17], indicating that participants experienced the game as engaging and motivating, despite the negative scenario.

Together, these findings suggest that the VR serious game provides an engaging and usable environment that supports flood-related awareness during response-oriented decision-making without excessive cognitive strain. User experience evaluation with particularly high stimulation scores indicates that active interaction with the simulated flood scenario was experienced as motivating despite the challenging context.

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