Heads-Up Computing Acessível: Um Jogo de Escape em Realidade Virtual Baseado em HMD para Pessoas Cegas

Accessible Heads-Up Computing: An HMD-Based VR Escape Game For Blind People

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Abstract. Introduction*: Head Mounted Displays often exclude visually impaired users due to their reliance on vision, affecting over 2.2 billion people worldwide. With the rise of Heads-Up Computing, which enables human-computer interaction through wearable technologies, this exclusion may become even more pronounced.* ***Objective:*** *This study focuses on developing an accessible virtual reality (VR) environment for blind users, guided by established game accessibility guidelines and principles of spatial cognition.* ***Methodology or Steps****: To validate the proposed approach, a prototype was developed and tested with both blind and sighted participants. The evaluation employed the sense of presence (IPQ) and a Game User Experience (UX) questionnaire.* ***Results:*** *The findings indicate that blind users achieved levels of user experience and immersion comparable to sighted users, highlighting the potential of inclusive design strategies in virtual environments.*
Keywords *Blind person, Visually Impaired, Escape Room, Games, Virtual Reality, Accessibility, Heads-Up Computing.*

Resumo. Introdução: *Dispositivos de realidade virtual* Head-Mounted Displays *(HMD) frequentemente excluem pessoas com deficiência visual devido à sua dependência da visão, afetando mais de 2,2 bilhões de indivíduos em todo o mundo. Com o avanço do conceito de* Heads-Up Computing*, que promove a interação humano-computador por meio de tecnologias vestíveis, essa exclusão tende a se intensificar.* ***Objetivo:*** *Este estudo tem como foco o desenvolvimento de um ambiente de Realidade Virtual (VR) acessível a usuários cegos, com base em diretrizes consolidadas de acessibilidade em jogos e em princípios de cognição espacial.* ***Metodologia ou Etapas****: Para validar a proposta, foi desenvolvido um protótipo, testado com participantes cegos e videntes. A avaliação utilizou o Questionário de Presença (IPQ) e um questionário de Experiência do Usuário (UX) em jogos.* ***Resultados:*** *Os resultados demonstram que os usuários cegos alcançaram níveis de experiência e imersão comparáveis aos dos usuários videntes, evidenciando o potencial de estratégias de design inclusivo em ambientes virtuais.*
Palavras-Chave *Pessoas cegas, Deficientes Visuais, Escape Room, Jogos, Realidade Virtual, Acessibilidade, Heads-Up Computing.*

1. Introduction

Heads-up computing proposes a human-centered approach in which humans use wearable devices instead of mobile phones to free themselves from the limitations of screen-focused interaction and manual occupation [Zhao et al. 2023]. This scenario is increasingly viable due to technological advancements such as the Meta Quest 3 and the Apple Vision Pro [Coronado et al. 2024a]. However, Head Mounted Displays (HMDs) inherently rely on visual input, which excludes users with visual impairments. As a result, the widespread adoption of this technology could negatively affect over 2.2 billion visually impaired individuals if accessibility is not adequately addressed in its design [Organization 2019]. In addition to being excluded from emerging technologies, visually impaired individuals often face barriers to accessing digital games, despite their strong interest in playing. According to Cairns [Cairns et al. 2021] and Guillen [Guillen et al. 2021], there is an increasing number of gamers with disabilities who engage in games for purposes such as entertainment, education, and exercise. This trend reinforces the demand for accessible design practices in game development.

In this context, this present work proposes the development of an accessible Virtual Reality (VR) environment for blind users. Achieving a satisfactory level of accessibility requires the application of established accessibility guidelines found in the literature. These accessibility guidelines are used to comprehend the end-user requirements of individuals living with disabilities [Chakraborty et al. 2017]. In addition to identifying user requirements, it is essential to understand how users navigate and interact with spatial environments. Spatial cognition refers to the mental processes involved in perceiving and reasoning about spatial information such as distances, directions, landmarks, object locations, and navigation strategies [Burgess 2008, Vasilyeva e Lourenco 2012]. By integrating insights from both game accessibility and spatial cognition, it is possible to design VR games that are inclusive and navigable for blind users.

Furthermore, selecting an engaging and motivating game genre enhances user experience. This study selects the Escape Room genre, in which "players discover clues, solve puzzles, and accomplish tasks in one or more rooms to achieve a specific goal (usually escaping from the room) within a limited amount of time" [Fotaris e Mastoras 2019, Coronado et al. 2023]. This genre promotes intrinsic motivation through the desire to win, overcome challenges, and explore out of curiosity and enjoyment [Vidergor 2021, Veldkamp et al. 2020]. Due to these characteristics, the Escape Room genre represents a promising direction for research in accessible game design.

2. Related Work

Relevant works have developed serious applications for visually impaired people. Nevertheless, this work takes into account four related studies: "X-Road" [Thevin et al. 2020], "Access to Escape" [Wiesemüller et al. 2023], "Loud and Clear" [Baas et al. 2019], and "The Legend of Iris" [Allain et al. 2015].

The first one is "X-Road", a virtual reality application that teaches visually impaired people to cross the street [Thevin et al. 2020]. The researchers shared specific design recommendations, from developing the prototypes to the experimentation phase.

The second one is “Access to Escape” [Wiesemüller et al. 2023], an Escape Room game in Virtual Reality for accessibility education. This research did not focus on providing an accessible environment. This escape room teaches accessibility guidelines through “inaccessible puzzles” that sighted players must improve [Mateen et al. 2023]. The third one is “Loud and Clear”, a virtual reality game with no visuals [Baas et al. 2019]. Its objective is to teach sighted users how a blind person feels and sees the world. It should be noted that blind people did not test this game, so it is not possible to determine whether it was accessible to them. The fourth one is “The Legend of Iris”, a game that employs an Oculus Rift [Allain et al. 2015]. The player’s objective is to locate the origin of a sound, navigate through moving objects while following the sound, and avoid moving objects while following the sound.

The four related studies are compared in the Table 1, which considers the following four factors: the utilization of game accessibility guidelines, the compatibility of the application for sighted and blind users, the classification of the game as an escape room, and the application of a user experience questionnaire. These four factors are considered when developing the VR Accessible Escape Game.

Tabela 1. Comparison

Artifact	Guidelines Usage	Accessible for All	Escape Room	UX Evaluation
Access to Escape	✓	✗	✓	✓
Loud and Clear	✗	✗	✓	✗
Legend of Iris	✗	✗	✗	✗
X-Road	✗	✓	✗	✓

3. VR Escape Game

The VR Escape Game is called “Escape-INF-VR”. A public video showcasing the VR game is available on Drive[1]. This game has been inspired by the infrastructure of the Institute of Informatics at the Federal University of Goiás (see Figure 1), and aims to mimic the real space by using a 1:1 scale [Coronado et al. 2024b]. This is a single-player game. The game route includes the following locations: Laboratory 256, the second-floor hallway, the stairs, the first-floor hallway, Laboratory 151, and the reception area. The game is based on the premise that a student from the Institute of Informatics fell asleep while writing an academic dissertation and is now attempting to leave the building.

To reach a certain level of accessibility, the prototype incorporates several game accessibility guidelines, which were collected from the literature [Coronado et al. 2023]. The prototype’s development is done through the Unity game engine (Editor Version 2021.3.31f1). And the game was developed for the Meta Quest 2 (Android platform).

The game implemented several guidelines which include “informing about object presence, using meaningful audio for game feedback, guiding by sound cues, providing a tutorial phase, using cooperative design” [Coronado et al. 2024b], allowing the movement through the controllers, setting text-to-speech instructions, providing feedback through

[1] https://tinyurl.com/Escape-VR

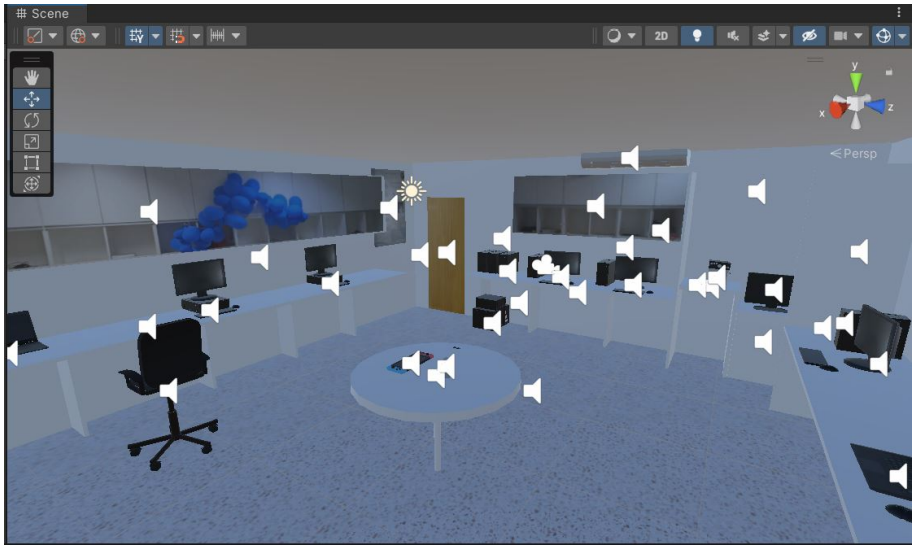

Figura 1. Escape-INF-VR Game

haptics, receiving diverse input, and supporting an assistive mode. It is also important to note that the prototype uses the principles of spatial cognition in its design. The individuals create a mental map of an environment in three stages: firstly, the individual defines some landmarks or points of reference, then connects the landmarks through some routes, and lastly, creates a global representation of the environment by joining various routes [May et al. 2020, Siegel e White 1975]. Therefore, setting specific reference points, such as static objects with 3D sounds, is essential.

Finally, the game implemented footsteps and collision sounds to give the player feedback on whether it is moving. Additionally, it is equipped with 3D audio sources and 2D audio on demand. It is imperative to note that an audio source accompanies the objects of significance. Furthermore, if the player is nearby and utilizes the controller, they can obtain feedback regarding the object's name. In this particular instance, the controller is configured to simulate a cane. The game incorporates a tutorial phase that introduces the fundamental mechanics of gameplay. The game is designed to receive three types of input: controller presses, controller movement, and voice commands. If a player requests assistance, they will be provided with an audio explanation of the necessary steps to proceed in the game. Additionally, if the player is unaware of their location, they can request their position and receive auditory confirmation. The game has been programmed to vibrate slightly when the user collides with an object. Also, the game includes a Multimodal Large Language Model that can describe the environment to the player from his point of view [Coronado et al. 2025].

4. Evaluation and Results

The sample size was limited to eight users per group. There are two sample groups, one consisting of visually impaired users (Group A) and the other composed of sighted users (Group B). The work employed two questionnaires: the GUESS-18 (Game User Experience Satisfaction Scale) [Keebler et al. 2020], and the Igroup Presence Questionnaire (IPQ) [Zhao et al. 2023, Thevin et al. 2020]. It is important to note that the GUESS-18 questionnaire evaluates the usability, narrative, play engrossment,

enjoyment, creative freedom, audio aesthetics, personal gratification, and the social connectivity of the game. Meanwhile, the IPQ measures the sense of presence inside a virtual environment through three subscales: Spatial Presence (SP), Involvement (INV), Experienced Realism (REAL), and a General item "sense of being there" (G).

Following Group A's results in the GUESS-18, the overall game score was 45.5, which represents 81.25% of the new maximum score (56) and 72.22% of the original score (63). Group B had an overall game score of 47.9, which represents 85.54% of the new maximum score (56) and 76.03% of the original score (63). As can be seen, the results are notably similar between the two groups. Considering the IPQ results, Group A got a mean of 5.56 in Spatial Presence, a mean of 5.88 in Involvement, a mean of 5.31 in Realism, and a mean of 6.13 in General. At the same time, Group B got a mean of 6.56 in Spatial Presence, a mean of 5.63 in Involvement, a mean of 4.34 in Realism, and a mean of 6.75 in General. The results are very similar but differ in Realism and Spatial Presence. Therefore, sighted users may have perceived less realism due to the quality of the textures and 3D models of the environment. However, they felt more spatially present in the environment than blind users.

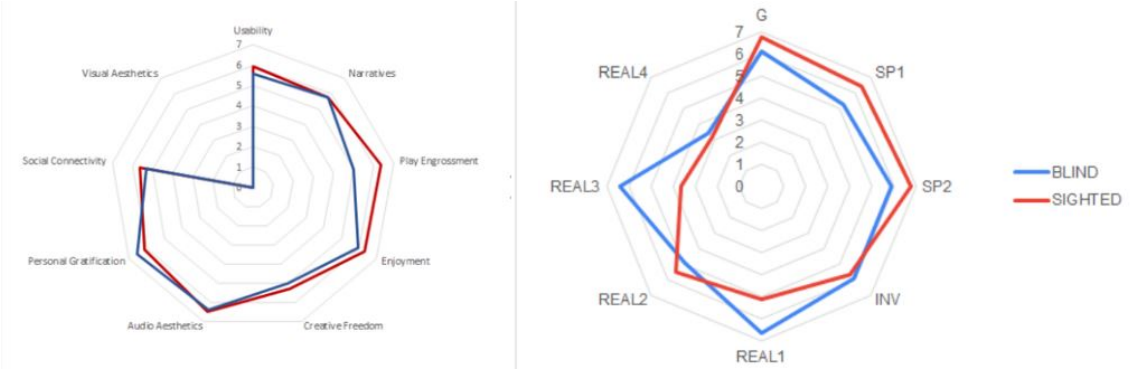

Figura 2. GUESS-18 (Left) and IPQ (Right) Results

5. Conclusion

The research proposal consisted of developing an accessible *Heads-up Computing* application through the application of accessibility guidelines and also by considering the principles of spatial cognition. Therefore, the application was evaluated through a usability (IPQ) and user experience questionnaire (GUESS-18) to assess the levels of immersion and the user experience of the blind (Group A) and sighted users (Group B).

Indeed, the game provided both groups with satisfactory immersion and presence and an overall positive user experience. The results suggest that the game can potentially be an accessible *Heads-up Computing* application.

The game "Escape-INF-VR" indicates that a *Heads-up Computing* application can be accessible to all by following the most commonly used guidelines outlined in the preceding section. Furthermore, this study reinforces the concept of universally accessible games [Grammenos et al. 2009], which means that games should be designed for all (sighted and blind individuals). In this case, the guidelines were selected to meet the specific needs of blind users. However, game accessibility guidelines also offer recommendations to accommodate other types of disabilities.

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