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Designing A VR-based Accessible Speed Of Light Exergame for People with Visual Impairments

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Abstract

Regular exercise is essential for health, but engaging in physical activities can be difficult for people with visual impairments due to accessibility barriers, limited opportunities, and sometimes safety reasons. As Virtual Reality (VR) games can offer a platform to promote body movement, we implemented a VR audio-based accessible Speed of Light game. We investigated three types of auditory feedback that convey the position of targets within a 3D space, exploring a horizontal interaction setting. A user study with 8 visually impaired participants revealed good performances and overall enjoyment of the game, especially when using verbal feedback (rather than sonification). This showcases how VR games with proper audio design can effectively promote the physical activity of people with visual impairments.

1 Introduction

Although exercise is necessary for being healthy, people with visual impairments (PVI) face various accessibility barriers, including safety issues (especially during outdoor physical activities). Thus, alternative forms of physical activity that can be done in more controlled environments may create further opportunities to practice exercise. Studies have shown that VR games help promote physical activity and stay healthy [1, 2]. However, traditional VR systems often rely on visual feedback, making it challenging for PVI to enjoy or access the game [3]. Therefore, recent research has focused on developing VR games that are more accessible to PVI [4, 5]. However, in most cases VR games have not been developed to promote physical activity. Moreover, while Wedoff et al. [5] attempted to help PVI engage in physical activity through VR games, they primarily used verbal feedback and did not design a variety of auditory feedback, which can greatly affect the user experience [6].

To address these challenges, we implemented a Speed of Light game specifically designed for PVI, aiming to promote physical movement. We incorporated three types of auditory feedback that convey the position of the active button in the 3D space. We focused on the horizontal plane (contrasting with prior work that focused on the vertical one [7]) as it is easier to distinguish azimuth (and depth) rather than elevation differences in 3D audio. We conducted a user study with 8 PVI participants to confirm the effectiveness and performance of the game. The results showed that while most participants found verbal feedback intuitive, sonification feedback was less intuitive but still maintained a high level of interest in the game. The contributions are as follows: (1) an evaluation of accessible VR games for PVI, and (2) an assessment of their potential to enhance health through VR games.

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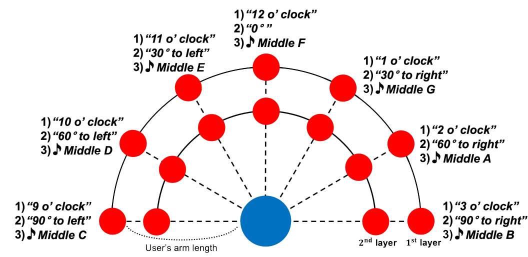

Figure 1: Sound scheme representing the target's location in each condition; 1) Ver_{clock}, 2) Ver_{degree}, 3) $Sonification$. Presents the xz-plane; the blue circle represents the user's head and red circles the targets. Seven targets appear in a 1^{st} layer in the simple scenario, and 14 appear in both the 1^{st} and 2^{nd} layers in the complex one.

2 User Study

2.1 Conditions

We designed three types of feedback to convey the target's 3d position as illustrated in Fig. 1. Ver_{clock} and Ver_{degree} provide the target's position with verbal feedback using the metaphor of a clock and degrees, while $Sonification$ conveys the target's position non-verbally through piano sounds. These include both a simple (1-layer) and a complex (2-layer) scenario.

2.2 Participants

We recruited 8 participants who are totally blind (3 females) whose average age was 30.9 (SD = 7.51; range 23-45). All but one participant were right-handed and had no prior VR experience. All had no auditory difficulties. Participants received $20 for their time.

2.3 Apparatus

For the experiment, we built a Unity application (version: 2021.3.15f) on a workstation with an AMD Ryzen 7 1700 CPU, 16GB of RAM, and an RTX2080 graphics card. We used Oculus Quest 2 to track participants' hands and head orientation and to provide auditory feedback. All objects in the game were identical in shape and size (*i.e.*, a cylinder with a 2-unit scale in unity). Objects were placed based on the arm's reach of each participant. Objects close to participants sound louder, while distant objects sound quieter, and all sound feedback was spatialized. Participants received different chime sounds when touching the correct and incorrect targets. They could request assistance by pressing the controller's trigger button to get verbal cues about the target's location relative to their hand. All logs, including incorrect interactions and help requests, were saved in a JSON file for analysis.

2.4 Procedure

An hour-long within-subject study began by signing a consent form for the experiment, followed by collecting the demographic information (e.g., age, gender, visual acuity). First, participants wore the head-mounted display and held the controllers in both hands to

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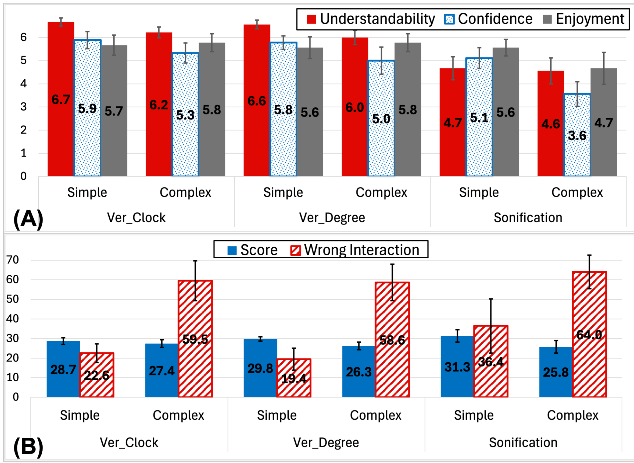

Figure 2: (A) The average scores for *Understandability*, *Confidence* (I think I was good at this game), and *Enjoyment*. (B) The average task performance for *Score* and *Wrong Interaction*.

calibrate the targets' position according to each participant's arm length. Then, they were asked to find as many targets as possible within the time limit with both a simple and complex scenario under all three conditions (after practice). The conditions were presented in a counterbalanced order using a Latin square design. Each target was active for 7 seconds, and if no target was found in that time, the next target appeared. Each trial took 60 seconds. Subjective ratings were collected at the end of each condition.

3 Findings

Fig. 2 shows the results of subjective ratings in a 7-point Likert scale (A) and participants' performance in terms of *scores* (correct interactions) and number of *wrong interactions (B)* in each scenario. We briefly summarize the main findings for each condition.

3.1 Ver$_{clock}$

Most participants stated that it was relatively easy to determine the target's location as they are used to the clock analogy. Yet, some participants mentioned that the game became boring as locating the target was too easy for a game that is expected to be challenging. Indeed, no one pressed the trigger button to request assistance. In addition, the number of wrong interactions increased in the complex scenario (in all conditions), as participants would hit the layer-1 targets when reaching for the layer-2 ones.

3.2 Ver$_{degree}$

Although not as intuitive as the Ver_{clock} condition, it was perceived to be easy to comprehend the location of the object. However, as representing an object's location in degrees was relatively unfamiliar to participants compared to Ver_{clock}, they showed some confusion. Moreover, participants found it more difficult to reach out to locations with angles such as 15°than 90°. Similar to the Ver_{clock} condition, the relative intuitiveness of this feedback condition reduces the long-term engagement of the game.

3.3 Sonification

Some participants noted that the sound in this condition was much shorter than that of verbal feedback. This was perceived to be positive when participants got used to it, as they could find the objects faster. However, it was difficult for participants to distinguish the sounds – eg., it was sometimes difficult to distinguish the piano note mapped to each angle. This resulted in participants requesting more assistance than in other conditions, confirming that sonification was less intuitive. On the other hand, one participant said that it was the most game-like experience, as it was more challenging.

4 Conclusion

We designed three types of auditory feedback for the Speed of Light game in VR. This feedback conveyed object positions in a 3D space, spread out horizontally, to provide an accessible exergame for PVI. We conducted a user study, which showed that most participants easily understood the target location and enjoyed the game regardless of the condition. Moreover, findings suggest that while Ver_{clock} and Ver_{degree} were intuitive, participants found it too easy to enjoy as a game. Instead,$Sonification$ condition, which was more challenging to understand the target location, was preferred.

Although we focused on designing one VR game to be accessible to PVI, our findings show that clock-based verbal feedback is effective for conveying the horizontal direction of an object in VR space but sonification, which requires some level of interpretation, might be a better option when finding the exact location is the goal of the game for users' engagement. As a future work, we will extend this work to promote full-body exercise in a 3D space, both vertical and horizontal). Moreover, reflecting prior studies suggesting guidelines of VR games for PVI [8, 9], we plan to conduct a long-term study to assess their lasting health effects.

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