Research and Analysis on the Design of VR Game Based Safety Education System for Color Blind Children

Haowen Wu

Faculty of Arts and Social Sciences, University of Sydney, Sydney, Australia
hawu0937@uni.sydney.edu.au

Abstract. In daily life, children's safety education generally depends on visual information, but the safety tips based on color have obvious limitations for children with color vision disorders. This study focuses on the potential safety problems of children with color vision disorders due to limited color recognition in their daily life, and discusses how to build a safe, immersive and repeatable learning environment for risk recognition through the design of virtual reality and game mechanism. In terms of specific research, this study first combs and analyzes the typical risk situations of color-blind children in the family and public places and summarizes the core needs of color-blind children in information perception. On this basis, combined with the barrier free design principles and relevant standards, a de color centered design framework for hazard warning is proposed. The framework constructs a set of risk identification mechanism that can replace the color prompt through the information of shape, icon, dynamic change and sound. The design is expected to help color blind children establish color independent risk identification ability and improve safety awareness. In addition, this study also attempts to provide a new path of integrating XR technology for safety education for special children, so as to expand the application boundary of digital technology in the field of education.

Keywords: Multi-sensory interaction, Barrier free design, Immersive experience, Gamification.

1. Introduction

Color vision defect is a kind of visual impairment caused by abnormal function of cone cells in the retina. Normal human vision depends on three kinds of cone cells, l cones, M cones and S cones. When one of the cone cells is abnormal or missing, different types of color blindness will occur [1]. Color vision defects usually do not exist in the black-and-white world, but the ability to distinguish specific color channels decreases. The most common is red and green color blindness. According to the data of the World Health Organization, about 8% of the global population has color vision defects in varying degrees [2]. At the same time, the safety information in reality has been highly dependent on color recognition for a long time, for example, red is often used for "no/stop/danger", yellow is often used for "warning/attention", green is often used for "safety/passage", etc. For people with congenital visual impairment, this means that a considerable number of children need to face the real dilemma caused by the failure of color information in the process of growth. For example, it is difficult to determine the size of the flame in the kitchen, whether the food is deteriorated, and it is difficult to distinguish the status of traffic lights on the road. The traditional safety education lacks the adaptation mechanism for color blind children, which virtually weakens their risk perception ability.

Traditional safety education and classroom teaching mostly rely on two-dimensional image interpretation, which is difficult to fully adapt to the visual cognitive characteristics of color-blind children. Virtual reality provides unique value for safety education. It can build high fidelity situations without real risks and allow repeated practice. In recent years, virtual reality has been widely used in the field of safety training and has been proved to significantly improve the learning effect and risk identification ability [3]. VR technology provides new possibilities for the education of special children by building an immersive and interactive situational environment. Head mounted virtual reality devices are of great value in education and training, especially in the fields of spatial cognition, operational skills and situational learning. Immersion and presence are important features of VR learning, which can improve learners' motivation and participation [4,5]. By simulating dangerous scenes in real life, VR can help children practice repeatedly in a safe environment, so as to establish more effective safety recognition and coping ability. Therefore, exploring the application of VR based game design in safety education for color blind children will not only help expand the research of XR technology in the field of special children, but also provide more intuitive and safe learning methods for color blind children. So, one of the core issues of this study is how to build a multi-sensory danger warning system for children with color vision disorders in VR environment without relying on color recognition. Second, on this basis, it explores whether the combination of Gamification mechanisms (such as levels, rewards, instant feedback and repeated practice) can improve children's understanding and memory of safety rules and their ability to migrate to real situations while ensuring playability.

2. Design method

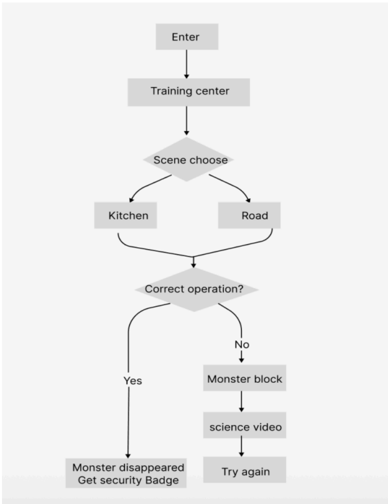

Figure 1. Flow chart of VR safety training based on Gamification mechanism (picture credit: original)

This design uses "risk monster" as a dangerous image carrier, and sets "detective goggles" as the medium. The overall interaction process of this study is shown in Figure 1. After clicking "enter game", the user first enters the training center. At this stage, basic operation teaching and situational introduction are provided to children to help them become familiar with interaction methods and task objectives. Then, the user enters the "scene selection" interface and can independently select different training scenes (such as kitchen or road), so as to enter the corresponding task level. In the specific task process, the system revolves around the core logic of discovery judgment disposal. Children need to identify the hazard sources represented by "risk monsters" in the scene and complete the task through correct operation (such as turning off the equipment, keeping distance or waiting for signals). When the player operates correctly, the monster gradually shrinks until it disappears. At the same time, the system gives the security badge as positive feedback to strengthen the learning motivation.

On the contrary, when the player makes a wrong operation, the system will not directly end the task, but will prompt the consequences of the wrong behavior through the negative feedback mechanism (such as monster getting bigger, blocking the path or escaping), and trigger popular science videos or prompt messages to guide children to understand the correct safety rules. Then the system provides the option of "retry immediately", enabling users to try again in a short time, forming a closed loop of error feedback practice. This process design reflects the learning-oriented game mechanism, turns errors into cognitive opportunities, and strengthens memory and understanding through instant feedback and repeated practice.

Barrier free information design emphasizes that color cannot be used as a unique code, and other clues are required as alternative channels [4]. The safety sign system is composed of geometric shapes, graphical symbols and colors. ISO standard states that the shape and color of safety signs shall follow the design principles, and specific safety symbols shall be registered. This means that shapes and symbols can provide accurate information even if color is not available [6]. This design explores whether the combination of multi-sensory cues and game mechanism can effectively help children establish safety cognition. Research shows that multi-sensory learning can significantly improve children's attention and information understanding ability, while immersive virtual environment can provide more situational and experiential learning methods, so as to improve the learning effect [4]. These ideas can support my design concept. Therefore, in terms of specific design strategies, this study first attempts to reduce the dependence on color information. All key judgment points must provide at least two non-color clues to meet the accessibility requirements of non-unique color information. Therefore, in the VR scene, the danger information will be expressed through morphological changes, icon prompts, flashing frequency or spatial position. Secondly, the design will introduce multi-sensory cueing mechanisms, such as voice reminders, vibration feedback or interactive tasks, to strengthen children's perception and memory of dangerous situations. Immersive VR research shows that in the virtual reality environment, with the increase of sensory cues and the improvement of simulation fidelity, the objective (total completion time) and subjective (average score of immersion) performance indicators are improved [7]. Third, the design will incorporate Gamification mechanisms, such as task challenges, role guidance and instant feedback [8]. The error does not end directly, but uses the process of visualization, popular science short video and immediate retry to build a learning closed loop, so that children can gradually master the safety identification strategy in the process of completing the task [9].

3. Design result

This study selected kitchen and road as the core training scenes, because these two kinds of environments are highly close to daily life and contain typical and high-frequency safety risks, which are suitable for the key situations of safety education for children with color vision disorders. The specific interaction design is shown in Table 1.

Table 1. Risk types, non-color tips and learning objectives in different scenarios

Scene	Risk points and objects	Non color hint design	Player actions and feedback	Corresponding learning point
Kitchen	Stove not closed	Vision: the fanged monster lies over the flame and dances constantly; Dynamics: monsters occupy scenes when touching flames	Correct: the player turns the stove switch → the monster gradually becomes smaller and disappears; Error: touch the flame → monster occupies the stove	Understanding turn off the fire source=eliminate the danger
Kitchen	Risk of electric shock from sockets/appliances	Vision: zigzag lightning monster with arc lines around; Dynamic: Monster high frequency jitter; Touch: strong vibration of the monster when the hand approaches	Correct: keep a safe distance or complete the task of power off/away from electrical appliances → the monster disappears; Error: the distance is too close → the vibration is enhanced and the warning prompt is triggered	Learn to recognize lightning symbols+warning signs=electrical hazards, and establish symbol recognition ability
Road	Pedestrian light red (stop)	Vision: the monster grows larger and blocks the road; Position prompt: the uppermost light is on;Interaction: attempts to advance will be bounced back	Correct: wait or back → enter the next stage after the vehicle passes; Error: forced forward → game failed	Understand that the upper light is on+the vehicle is running=not passable, and establish the location rules of traffic signals
Road	Pedestrian light green light (passage)	Vision: monsters guard both sides of the road; Position prompt: the lowest light is on, and the monster produces luminous effect	Correct: observe the vehicle stop → cross the zebra crossing	Understand that the light below is on+the vehicle is stopped=it is passable, and learn the rules of safe crossing the road
Road	Hazardous area entrance/no go sign	Vision: the barrier wall monster blocks the entrance; Symbol hint: circle slash (Forbidden symbol); Tactility: slight vibration near the entrance	Correct: identify the forbidden signs and bypass → get rewards; Error: trying to cross → blocked and prompted	Learning forbidden symbol=no entry, from relying on color to graphic symbol recognition rules

3.1. Kitchen scene

The kitchen scene mainly focuses on the common hazards in the home environment, such as fire and electrical risks. In visual design, danger does not rely on color cues, but is expressed through shape, dynamics and position changes. In the task of "the stove is not closed", a sharp tooth monster will appear above the flame, forming an obvious dynamic visual prompt (as shown in Figure 2). At the interactive level, children need to turn off the fire source by rotating the stove switch. When the operation is correct, the monster gradually shrinks and disappears. If people touch the flame area by mistake, the monster will expand and occupy the stove and trigger a prompt message and popular science video to explain the fire hazard. In addition, in the hazardous task of sockets and electrical appliances, the system indicates potential risks through zigzag contour, flicker frequency and local vibration feedback. Children need to keep a safe distance or perform power-off operation to help children establish the ability to recognize electrical hazards and warning signs. In general, the kitchen scene focuses on training children's ability to identify and handle hazards and operational risks.

Figure 2. Kitchen UI interface (picture credit: original)

3.2. Kitchen scene

The road scene mainly simulates the dynamic risks in the traffic environment, such as traffic lights and vehicle traffic rules. In the task of red-light prohibiting advance, the system conveys the impassable information through the interactive feedback that the top light is on, the monster gradually becomes larger and blocks the road, and the player will be bounced back when trying to advance (as shown in Figure 3). Children need to complete the correct decision through waiting behavior, so as to make the monster disappear and enter the next stage. On the contrary, if forced forward, it will be judged as an error and trigger the failure and retry mechanism. In the task of green light passing, the system will prompt the passable status by the way of the signal below is on, the monster produces a luminous effect, etc. Children need to observe environmental changes and pass the zebra crossing at the right time to establish their understanding of traffic rules. In addition, the system introduces standardized symbols (such as circle slash) as key prompts in the task of hazardous area entrance and prohibition signs, emphasizing the transformation from color recognition to symbol recognition. Children should identify signs and avoid entering hazardous areas, otherwise they will be blocked and receive prompt feedback. This scene focuses on training children's ability to understand and apply dynamic environment and regular information.

Figure 3. Road UI interface (picture credit: original)

At the application level, the design can be used not only for daily safety training accompanied by parents in the family scene, but also for special education institutions, rehabilitation centers and school assisted teaching environment, providing a visual teaching tool for teachers. At the same time, the immersive and playful mechanism based on VR can effectively improve children's participation and learning motivation and make safety education change from passive acceptance to active exploration. The empirical study on children's traffic safety shows that children trained in VR have significantly improved in risk perception and decision-making performance. Especially after repeated training, its performance can gradually approach the level of adults in similar tasks [10]. In addition, this study provides a replicable design paradigm for the application of XR technology in the education of special children, that is; by removing the dependence on single perception, it turns to multimodal perception and situational learning. This not only helps to expand the research path of barrier free design but also provides reference and inspiration for the future application in other groups with sensory impairment (such as hearing-impaired or cognitive impaired children), so as to promote the closer integration between technology and social care.

4. Conclusion

This study focuses on the safety problems faced by children with color vision disorders due to their limited color recognition in daily life and discusses the application potential of VR and Gamification mechanism in safety education. By analyzing the perception characteristics and risk identification needs of CVD children, this paper proposes a de color centered design idea and constructs a VR training system with multi-sensory interaction as the core. However, this study still has some limitations. Firstly, the current design is mainly based on theoretical analysis and prototype construction, lacking large-scale user experimental verification, and its actual learning effect and long-term impact still need further empirical research support. Secondly, there are still differences between VR environment and real situation. Whether children's cognition formed in virtual environment can stably migrate to the real world is still a question to be discussed in depth. Future research can be further expanded from many directions. First, people can evaluate the actual effect of CVD children of different ages through user experiments and research and optimize the interaction design. Secondly, the future design can be extended to more life scenes (such as campus, etc.). In addition, the learning mode of integrating AR with the real environment is also expected to further enhance the authenticity of the learning situation.

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