A Stroop-based Long-term Cognitive Training Game for the Elderly in Head-mounted Displays

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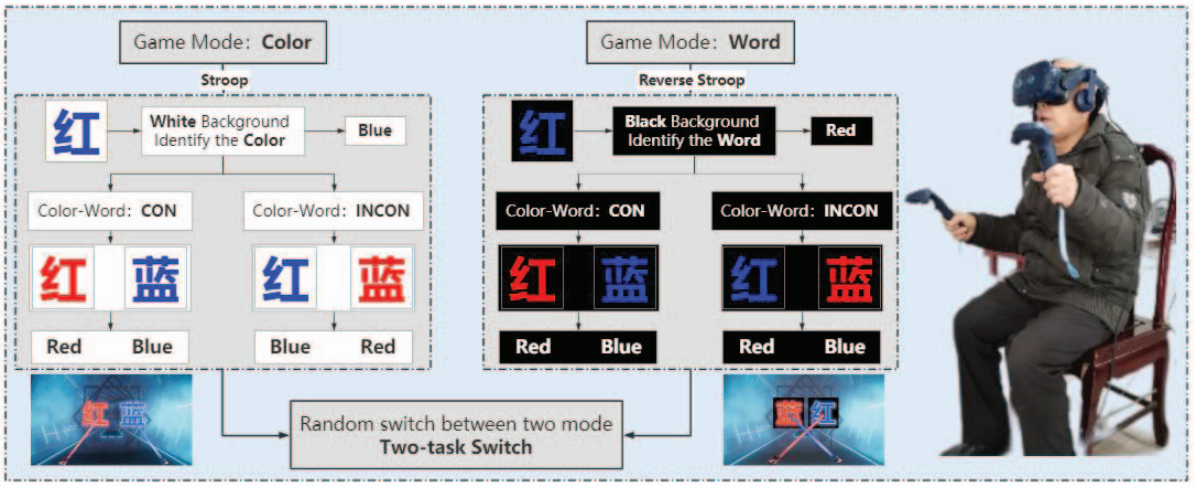

Figure 1: System Design: Color mode based on Stroop paradigm and Word mode based on Reverse Stroop paradigm (CON: Consistent, INCON: Inconsistent). Game scenes and senior-friendly operation.

Abstract

Virtual reality (VR) games have been increasingly incorporated into the cognitive training of the elderly because of their unique immersion and interactivity. However, previous studies have focused on existing commercial games, which are not suitable for the elderly. Due to the progressive decline in cognitive abilities and inflexible action of the elderly, we propose a VR music game (LightSword) based on two classical psychological paradigms (Dual-task and Stroop). To enable long-term cognitive training of the elderly in a playful and relaxed virtual environment, the game integrates easy interactions, motivating mechanisms with real-time feedback, and pleasant music. The results of the prior study show a linear increase in game performance scores which are related to cognitive ability, demonstrating the potential of the proposed game for cognitive training.

Index Terms: Human-centered computing—Interaction design—Interaction design process and methods—User centered design;

1 Introduction

Executive function is the most advanced cognitive activity in the brain, which is composed of inhibitory control, working memory, and cognitive flexibility [1]. Inhibitory control is a crucial part of executive function. It is divided into conflict inhibition and response inhibition. Numerous studies have focused on the inhibitory function to improve cognitive performance in the elderly. Cognitive and physical exercise have been widely proven, as non-pharmacological methods, which could effectively prevent dementia and slow down age-related cognitive decline. In recent years, experts have proved VR games can enhance the training effects by stimulating four different cognitive processes: attention, memory, language, and visuospatial perception. However, most previous VR cognitive training employed commercial games [2], which were unsuitable for long-term training of the elderly.

In this paper, we propose a novel playful VR cognitive system that combines the targeted psychology paradigm (Dual-task and Stroop), pleasant virtual scenery, motivating mechanisms with real-time feedback, and enjoyable music. To evaluate the system, we conduct a prior experiment. Preliminary results show game performance scores climb linearly as the number of training sessions increases. This improvement implies that the Stroop interference effect becomes smaller in trained elderly people, directly reflecting the benefit of conflict regulation ability [3]. These findings demonstrate that our system is friendly for long-term training of the elderly and provide evidence of the potential of the VR system to improve cognitive performance.

2 System Design and Implementation

We design a VR game system called LightSword using Unity3D, which increases motivation and engagement among the elderly.

2.1 The selection of psychological paradigm

Inspired by the BeatSaber, we aim to build a VR cognitive training system suitable for the elderly. First, we add the Dual-task paradigm to the game, so that the elderly need to identify the content of the block while hitting the target. Humans regularly challenge these control processes when attempting to simultaneously accomplish

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multiple goals, generating interference as the result of fundamental information processing limitations [4]. Meanwhile, targeting inhibitory control, we choose the Stroop paradigm (Color mode: Identity the color ignore the word) and the Reverse Stroop paradigm (Word mode: Identify the word ignore the color) [2]. When the Stroop effect occurs, the elderly's selective attention and conflict control mechanisms are simultaneously engaged. The elderly are trained by switching randomly between color and word modes to prevent experience effects, which means that players do not need to think, but play through prior experience.

2.2 The visual and interaction design

We simplify the virtual scenery and UI components to reduce dizziness caused by highly active game scenery. The background of the game is a blue channel, which adds dynamic bubbles and smoke to make the environment more realistic and vivid. In our game, the blocks fly in a linear from the two channels in front of the player's eyes, accompanied by music. Because of the inflexible action of the elderly, we allow the elderly to sit to finish the game, using a simple interaction approach (wave the handle) to assure safety and exercise at the same time. Simultaneously, our game incorporates real-time feedback. A bubble effect will appear when seniors hit the target correctly five times in a row, and the real-time feedback will provide positive encouragement which can boost their motivation and sense of accomplishment. What's more, this game provides music that the elderly appreciate. With a simple change of music, the user might have a whole new experience.

2.3 The game difficulty and scoring mechanism

According to Seligman's "PERMA" theory, activities that allow the user to float in their Flow Zone (defined as a high level of enjoyment with a balance between the task's difficulty and the person's abilities) are included [5]. The person is pleasantly challenged and highly engaged by the job while experiencing high degrees of enjoyment in this state of flow. Maintaining a feeling of flow is critical for users to persist in cognitive training. Considering the slow reaction speed and the increasingly weakened cognitive ability of the elderly, we set three-game difficulties. In easy mode, inconsistent blocks stood 20-30% of the total blocks, the distance between the former and the latter block was more than 60 cm, and the flight time of the blocks was more than 2 seconds. In normal, 30-40%, 50-60cm,1.5-2 seconds; In hard, 40-50%, 40-50cm, 1-2 seconds.

The elderly were trained by using the HTC VIVE's controllers, which are mapped as the lightsaber in the virtual world. The players hold a red lightsaber in their left hand and a blue lightsaber in their right hand. When the lightsaber clashes with the block, the players get the corresponding score. Set the score for each block separately: 60+25+15. The players will gain 60 points if they correctly judged the block. Cutting speed is worth 25 points (if players hit the block in less than 1 second, they'll gain 25 points). And the cutting point must be in the center of the target (10cm*10cm) is worth 15 points. It's will be recorded as the GREAT if players get more than 60 points, but if they don't hit the block, will be recorded as the MISS.

3 Prior Experiment and Results

Our training system is built on a computer and the elderly use the Head-Mounted Display (HMD) and the controllers for game training. We conducted a prior study on the elderly to evaluate the system's effectiveness in enhancing cognitive ability. We recruited five elderly people, who were trained for ten sessions (Five sessions in easy mode, followed by five sessions in normal mode). For the analysis, we mostly employed game performance scores (GS). Figure 2 shows the correlation between GS and the number of training sessions.

$$GS = \frac{cor}{total} * 2 - \frac{fault}{total} - \frac{miss}{total} + \frac{great}{total} * 3 \qquad (1)$$

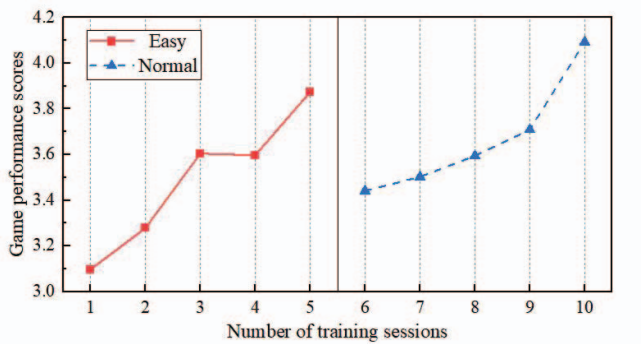

Figure 2: The correlation between GS and the number of training sessions, with five sessions for easy, followed by five sessions for normal.

Cor: the number of correct blocks. Fault: the number of fault blocks. Miss: the number of missing blocks. Great: the number of great blocks.

4 Conclusion and Future Work

We develop a customized VR cognitive training system for the elderly, which combines the targeted psychology paradigm, pleasant virtual scenery, motivating mechanisms with real-time feedback, and enjoyable music. According to Seligman's "PERMA" theory, considering the gradually declining cognitive abilities of the elderly, we set three reasonable and progressively increasing levels of difficulty that allow them to maintain a high level of enjoyment while achieving a balance between the tasks' difficulty and their capabilities. These unique designs allow the elderly to train for the long term without boredom and fatigue. According to preliminary results, game performance scores climb linearly as the number of training sessions increases. These findings demonstrate that our system is friendly for long-term training of the elderly and provide evidence of the potential of the VR system to improve cognitive performance in the elderly.

In the future, we will conduct user studies to investigate whether the system is sustainable and transferable in terms of improving cognitive performance in the elderly. In addition, we will also investigate whether the system is sensitive to age-related cognitive decline.

Acknowledgments

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