Improving Cognitive and Emotional State Using 3D Virtual Reality Orientation Game

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Abstract. Patients suffering from Alzheimer's Disease (AD) exhibit an impairment in performing tasks related to spatial navigation. Tasks which require navigational skills by building a cognitive map of the surrounding are found effective in cognitive training. In this paper we investigated the effect of cognitive training using a fully immersive 3D VR orientation game. We implemented an intelligent guidance system which helps to reduce the negative emotions if the participants experience difficulty completing the quests of the game. We found that after playing the orientation game, participants performed better in memory and in certain attention exercises. We also studied the effects of guidance system to reduce the frustration during cognitive training using VR environments.

Keywords: Virtual Reality · Orientation · EEG · Immersive environment · Game adaptation · Assistance system

1 Introduction

The ability to find one's way using spatial reference frames and cues from our surrounding is a complex cognitive process. Studies show that navigational skills decline with ageing [1]. However, people with Alzheimer's disease (AD) display a significantly higher decline, which is also one of the early symptoms of the disease. Research shows that spatial navigation training programs in older persons led to improvements in spatial performances [2].

Virtual Reality (VR) applications can be used to address the challenges of cognitive training of dementia patients due to a high level of interaction possible within a virtual environment (VE) without being in any risk otherwise posed by real-life surroundings. In this paper, we present a fully immersive VE where the participant must find items of interest in a public garden. However, navigating in an unfamiliar place can be challenging, consequently leading to higher negative emotions and a tendency to give up

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before completing the experiment. Research shows that it is more beneficial for patients with cognitive impairment to be helped through the completion of a challenge, rather than see the challenge failed [3]. It is important to present both audio and visual cues to cater to the needs of a specific profile of patients suffering from either visual or auditory impairments [4]. Thus, real-time assistance with audio and visual feedback is one of the mandatory components in games for elders, to incorporate mechanism which achieves high-level engagement by keeping player filled with positive emotions. Hence, we implemented an intelligent guidance system based on participant's behavior, that helps them to complete the tasks without being explicitly asked for help.

Our goal for this study is to investigate the effect of the orientation game and the guidance system on the cognitive functions of people suffering from subjective cognitive decline (SCD), a preclinical state of possible Alzheimer's Disease (AD). We state our research objectives as the following: **Q1: is it possible to stimulate the brain using a virtual maze game in order to enhance attention and memory? Q2: is it possible to help participants in order to reduce negative emotions?**

The rest of this paper is organized as follows. In Sect. 2, we discuss the related works and the cognitive map theory. In Sect. 3, we describe the orientation game: the environment, the objectives and the guidance system. In Sect. 4, we detail the cognitive tests and the experimental procedure undertaken to validate our hypotheses. Finally, in Sect. 5 we present and discuss the obtained results.

2 Related Works

According to the cognitive map theory, the formation of representations of spatial information – in other words, the creation of a cognitive map – helps reduce cognitive load and increases recall and the encoding of novel information [5, 6]. Studies report that decreases in the volume of the hippocampus – a structure playing a key role in memory – correlate with a decline in cognitive function. Indeed, it is speculated that increasing grey matter in the hippocampus could entail better memory [7]. Interestingly, playing 3D video games over a period, such as Super Mario 64, reportedly increases hippocampal volume [8], as well as increases performance in episodic and spatial memory quests. It is speculated that 3D games, such as Super Mario 64, lead players to create a cognitive map of the environment.

It has been observed that virtual reality environments (VE) lead to formation of cognitive maps similar to the real environments [9]. This makes VR games ideal for simulating real life scenarios for cognitive training of elderly. Certain VR applications have concentrated on games focused on performing activities of daily life such as cooking, driving and shopping [10]. Another key advantage of using VE is that they offer a safe way to achieve high level of interaction adaptable to the characteristics and needs of individual patients [10, 11]. A fully immersive VE offers higher sense of 'presence' and interaction which subsequently affects the behavioral responses of patients.

3 Orientation Game

3.1 Environment: Orientation Game

The fully immersive VR environment simulates a botanical garden in the form of a 5 × 5 maze. In this environment, trees form the walls of the maze and clearings through the trees are the pathways. The participant starts at one end of the garden and has to navigate using a joystick by clicking in the direction in which he/she intends to move. Other elements in the game are: 1) a map of the garden with geographical directions, 2) the position and direction of the user shown by a red arrow in the map, 3) a flashing blue circle representing the location of the items, 4) visual hints displayed when needed and, 5) verbal messages to the participant.

The game starts with a tutorial to let the users familiarize themselves with the environment and the controls. It consists of four quests. For the first three quests, the participant is asked to collect an item located at a specific location of the 5 × 5 maze. We display the name of the item and its location by a flashing blue circle on the map for 5 s. The user needs to reach the location and collect the requested item. When the item is collected, we remove it from the list and display the next item and its location.

3.2 Guidance System

We implemented a rule-based guidance system that provides navigational hints or audio and visual messages to the participants and helps them in completing the quests. It actively monitors the participant's emotions, namely frustration, excitement, engagement, meditation, and valence using Emotiv electroencephalograph (EEG) headset data in real-time. On sensing a situation where the participant may need a hint, it sends a message to the VR system, which displays the hints in form of location in the map or audio and visual messages in case of text-based hints. Figure 1 shows the different hints provided by the guidance system.

Hint levels		Participant's position	Object's location	Message (Audio and Visual)	Highlighted Path in Map
Level 1		✓	✓		
Level 2	2-1	✓	✓	*Please check the position of object on the map.*	
	2-2	✓	✓	*You are too far. Try to take few steps back.*	
	2-3	✓	✓	*1. Good job! Almost there.* *2. Keep up the good work* *3. You are going in right direction*	
Level 3		✓		*Follow the displayed path. The object is somewhere nearby.*	Path to cell nearest to target object
Level 4		✓		*Follow the given path to find the object*	Complete path to the object.

Fig. 1. Different level of hints

The hints provided by the guidance system are activated in three different cases:

1. Emotions: At every second, the mean of the change and the rate of the change of emotion values in past ten seconds are used to calculate a net score for each

emotion. The emotion with the maximum score is compared with an empirically defined threshold to activate the emotion-based hints.
2. Away from target: If the participant takes three steps or more, all of which are at four blocks or more from the target, the map displaying target location is activated.
3. No Movement: If the participant doesn't move for more than a given amount of time, the map displaying target location is activated.

The details change with different levels of hints provided by the guidance system. Level 1 provides the least information and displays only the participant's location and the object's location on the map. Additionally, level 2 displays a text message in a prompt in the VR environment along with the verbal narration of the message. Level 3 hint highlights a path in the map, which the participant can follow to reach a location immediately next to the actual location of the object. This leaves some scope of exploration and the participant needs to search for the object in all possible directions. Level 4 hint highlights the complete path leading to the object's location on the map.

In case of activation based on participant's emotion, if the hint is triggered by frustration, the level of hint increases which provides more details to find the object. On the other hand, if the hint is triggered by positive emotions such as excitement or engagement, the level of hint decreases. In case of hint activated due to no movement of the participant, the level increases every fifteen seconds till the participant moves. When the participant is away from the object as determined by the guidance system, the hint provided is always level 2-1.

4 Experiments

Since our main goal is to analyze the impact of orientation therapy and building a cognitive map on the attention and memory performances, we developed 3 attention exercises and 3 memory exercises to compare participants' performances before and after playing the game. We tested our approach with 15 participants (11 females) with subjective cognitive decline (SCD) and a mean age = 73.4 (SD = 5.73).

The participants took part in two sessions. In the first session, we performed some assessments to ensure that they were eligible to conduct the experiments. During the second session (experimental session), the participants were invited to fill a pre-experiment form. Afterwards, we equipped them with an EEG headset, and they start resolving attention and memory exercises. When they complete the exercises, we equip them with Fove VR headset, and they start the Orientation Game. Following the game, we removed the Fove VR headset and the participants were asked to complete the attention and memory exercises again but with different examples. Finally, we remove the EEG headset and the fill up a post-experiment form.

5 Results and Discussion

In order to study the enhancement in attention and memory, we analyzed performance improvement before and after the orientation therapy of the first three exercises (Attention exercises). On exercise 1, the general mean improvement was 6.67%. on the second exercise, there was a mean improvement of 0.61%. And the performance improvement of the third exercise was 0%. We also analyzed the performance improvement before and after the orientation therapy of the memory exercises (exercise 4, 5 and 6). For the fourth exercise, the mean improvement was 1.11%. For the fifth exercise, the mean improvement was 12%. Finally, the mean improvement is 26.67% for exercise 6 which is the highest percentage of improvement. These results show increase of memory performance following the orientation therapy and an improvement in attention abilities in certain participants.

Next, we analyzed the frustration of the participants before and after the hints are provided. As shown in Fig. 2, the guidance system provided at least one or more hints to 9 out of the 15 participants. In the rest of the cases, participants didn't have any difficulty in completing the quests.

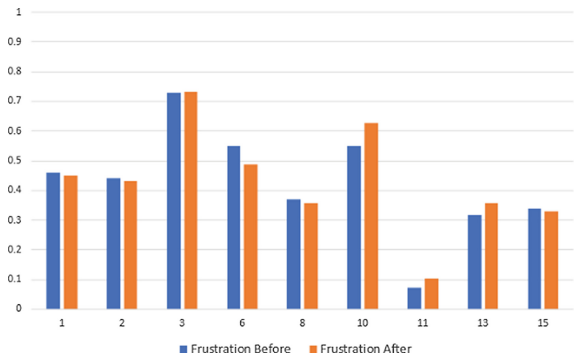

Fig. 2. Average values of frustrations of each participant, ten seconds before and after the hints

We notice that in 6 out of 9 participants, frustration values in next ten seconds decreased for the hints provided to them. Participants 8, 10, 11 and 13 were respectively provided one, two, one, and one hint, while the rest of the participants received at least five or more hints. For the different types of hints, we observed that except for hint level 2-2 and hint level 4, the average values of frustration for all the participants were lesser in the next ten seconds after the hints were provided. Hint level 2-2 provides a warning message: 'You're too far. Try to take few steps back.'. This led the participants to believe that they might be doing something wrong leading to higher frustration. Hint level 4 displays the complete path to the item's location. But, since we configured the hint to appear for only four seconds, it was not enough for the participants to memorize the complete path, which may lead to a more frustration.

6 Conclusion

In this paper, we designed a 3D VR orientation game in with real-time guidance system which can be used for cognitive training of the patients suffering from pre-clinical states of Alzheimer's disease. The results show an improvement in memory performance for most of the participants, and better attention abilities for some of the participants after the therapy. The guidance system is effective in reducing the frustration while solving quests of the game. In some cases, the decrease is not significant, but the stabilization of frustration after a continuous increase after the hint is provided shows the usefulness of hints. Also, the increase in negative emotions after two hints shows that hints need to be carefully designed to give positive messages and the time taken to understand the hints should be taken in consideration.

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