Developing a Virtual Reality System to Alleviate Mild Cognitive Impairment in China

Emergent Research Forum (ERF) paper

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Abstract

The purpose of this study is to design a virtual reality (VR) system that can be used to alleviate aging-based mild cognitive impairment problem among senior citizens in China. We integrated different memory types and models with our VR design and conducted a pilot test to evaluate the effectiveness of the VR system with 120 senior people. This is one of the first studies attempting to integrate memory theories in VR design. It can provide an excellent foundation to contribute to the growing body of design science research (DSR) papers and have significant practical implications.

Keywords

Virtual reality, cognitive impairment, long-term and short-term memory, system design

Introduction

The recent years have witnessed escalating medical costs worldwide due to the elderly population increase. As people age, their cognitive capacity gradually declines, eventually leading to cognitive impairment and even mental illnesses such as dementia. Cognitive impairment ranges from mild to severe. With mild cognitive impairment (MCI), people may begin to notice changes in cognitive functions, but are still able to handle their everyday activities. MCI is the early stage of cognitive decline and has a significant risk of converting to dementia. It defines the grey area between intact cognitive functioning and clinical dementia (Petersen et al, 2014). No medications are currently approved by the U.S. Food and Drug Administration (FDA) to treat mild cognitive impairment. Some drugs have been approved to treat Alzheimer symptoms, but have not shown any lasting benefit in delaying or preventing the progression from MCI to dementia (Alz, 2018).

The aging-associated cognitive impairment threat is particularly serious in China. Over the past few decades, the age structure of the Chinese population has changed drastically, with large decreases in mortality and increases in life expectancy (World Bank, 2016). Research shows that the economic and social impact of the population aging in China is increasing year by year. The cost for China's medical care treatment and service as a share of GDP will increase from 6.97% in 2015 to 21.77% in 2050 (Li et al, 2014). According to the United Nations, China is ageing more rapidly than almost any country in recent history. It is therefore not surprising that the epidemic of ageing-related diseases, especially cognitive disorders, is rising rapidly in the country (Nie et al, 2011). Such cognitive disorders tremendously affect the quality of life of older people and lead to many economic and public health issues.

Given the serious consequence of cognitive impairments and the lack of effective medical treatments, it is imperative to develop alternative interventions to at least mitigate cognitive impairment among older people. Some suggest that information technology applications could be a game changer for dementia treatment research (Morgan, 2016). It is possible to apply virtual reality (VR) to address the aging based

MCI problem. Therefore, the objective of this study is to design a VR system that can be used to alleviate aging-based MCI among the older people in China. We first provide an overview of current practice of using VR in addressing cognitive impairment issues. We then explain the biological mechanism behind cognitive impairment and memory loss. Following that, we describe how we design a VR system intended to mitigate the MCI problems in China.

Virtual Reality (VR) and Cognitive Impairment

VR refers to the use of interactive simulations created with computer software and hardware to present users with opportunities to engage in environments with objects and events that appear and feel like the real world (Weiss and Jessel, 1998). VR can play an important role in the rehabilitation of psychological functions due to a creation of synthetic environments where it is possible to carry out tasks very similar to the ones experienced in the real objective and social world (Castelnuovo et al, 2003).

VR as MCI assessment and intervention tools

Some studies are focused on using VR as a screening or assessment tool. Cushman et al (2008) found virtual environment testing provides a valid assessment of personal navigational skills. Werner et al (2009) showed that the virtual action planning supermarket, a VR-based software, is a viable tool to assess executive functioning (EF) deficits in patients with MCI and healthy elderly. Weniger et al.'s (2011) study demonstrated that VR environments have a major advantage in assessing users' spatial navigation and memory formation. Plancher et al. (2012) conducted studies with three groups of people under two virtual environments and their findings provided additional insight into the early diagnosis and rehabilitation of pathological aging, especially from the memory assessment perspective. Zygouris et al. (2015) showed that a VR cognitive training application, the virtual supermarket, can be used as a screening tool for MCI. Morgan (2016) designed "Sea Hero Quest", a VR game to collect data for navigational skills, one of the first symptoms of dementia from a large population.

Some studies used VR as an intervention tool in cognitive training programs. Schreiber et al (1999) compared seven individuals living with Alzheimer's disease or vascular dementia using a VR program (IG) with another seven individuals living with Alzheimer's disease or vascular dementia using active control (CG) and found that IG group improved immediate recall of visual information and delayed recall of topographic information. Optale et al. (2010) conducted an experiment on 31 individuals with verbal memory impairment, in which 15 were exposed to VR environments familiar settings (e.g. home, garden) training (intervention group, IG) and the other 16 to music therapy training sessions (control group, CG). They found that the IG showed significant improvements in general cognition and verbal memory post training (PT) and post booster (PB) where CG showed decline. In another experiment, Man et al. (2012) compared 20 individuals with MCI using VR program (participants required to navigate home and shop environments) (IG) with 24 individuals with MCI using active control (therapist led memory training using print images) which matched the VR program (CG). Their results showed that both IG and CG benefited from memory training, scored for immediate and delayed recall improving, and IG improved on perceived use of memory strategy.

VR and MCI in China

The use of VR for MCI is still at the very early stage in China. The development of VR in addressing the cognitive impairment problem in China is at its infancy, few studies have been conducted and little information is available in the literature. This provides a great opportunity for researchers to conduct studies in this arena.

Mild Cognitive Impairment (MCI) and Memory

Mild cognitive impairment (MCI) causes people a slight but noticeable and measurable decline in memory or cognitive abilities. MCI patients can be categorized into two subtypes: amnestic MCI (aMCI) if they have a prominent memory impairment, either alone or with other cognitive impairments (multiple domains with amnesia), or nonamnestic (naMCI) if a single nonmemory domain is impaired alone or in combination with other nonmemory deficits (multiple domains without amnesia) (Rozzini et al, 2008). There is growing evidence that aMCI is associated with biomarkers for Alzheimer's disease, while naMCI maps more closely to cerebrovascular disease (Hughes, et al, 2011). The sizes of the hippocampus, the entorhinal cortex and the amygdala were decreased in aMCI relative to naMCI (Csukly et al, 2016). aMCI is more likely to progress to dementia than the naMCI (Hughes, et al, 2011). In this study, we focus on developing a VR system to address the memory impairment problem associated with aMCI.

Memory types and related models

The traditional multi-store memory (MSM) model developed by Atkinson and Shiffrin (1968) includes three different phases of memory: sensory memory, short-term memory, and long-term memory. Sensory memory is the shortest-term element of memory and allows individuals to retain impressions of sensory information gathered from five traditional senses after the original stimulus has ceased. Short-term memory is the capacity for holding a limited amount of information in a very accessible state temporarily. Long-term memory is the phase or type of memory responsible for the storage of information for an extended period of time.

The MSM model suggests that both short-term and long-term memory each operate in a single, uniform fashion. Baddeley and Hitch (1974) challenged the ideas of Atkinson and Shiffrin's and argued that short-term memory has more than one component. They replaced short-term memory with working memory, a type of memory with a limited capacity that is responsible for temporarily holding information available for processing. In the literature, working memory is not completely differentiated from short-term memory and the two are often used synonymously (Miyake and Shah, 1999). However, different from working memory model working memory is not a unitary store. While short-term memory stores a limited amount of information, working memory allows for the manipulation of stored information (Cowan, 2008). Working memory is important for reasoning and decision making (Diamond, 2013).

Long-term memory can be split up into explicit (or declarative) memory and implicit (or procedural) memory. These two different types of LTM are stored in different regions of the brain and undergo quite different processes. Declarative memories ("knowing what") are associated with the hippocampus and frontal lobes areas of the brain. Procedural memories ("knowing how"), is the unconscious memory of skills and how to do things, on the other hand, do not appear to involve the hippocampus at all, and are mainly encoded and stored by the brain's cerebellum and basal ganglia areas (Myers and DeWall, 2017). When MCI occurs, individuals' memory functions are undermined. The good news is that memory ability can be retained and strengthened through training. In this study, we attempt to design a VR system to enhance these different types of memory ability so that MCI is mitigated.

VR System Development

We follow the design science research (DSR) process (problem identification & motivation, objectives of a solution, design & development, demonstration, evaluation, and communication) suggested by Peffers et al. (2008) in our VR system development. Due to the five-page limit set by AMCIS ERF paper, we only provide some development background information here. We decided to use supermarket as the setting of our VR system. This decision is based on theoretical, practical, and technical considerations. Theoretically, previous studies have suggested that the supermarket is a viable real world setting to simulate in a VR environment for MCI interventions (e.g. Werner et al, 2009; Zygouris et al., 2015). Practically, for older people in China, supermarket is a familiar environment as they buy groceries almost every day. Technically, given the large variety of items in a supermarket, many memory improvement techniques can be integrated into this setting. In addition, we consulted with an expert panel including two neurologists, two family doctors, and two senior center nurses, and they confirmed the appropriateness of this choice.

Based on the working memory model (Baddeley and Hitch 1974), we designed components that attempt to enhance the four different types of memories: sensory memory, working memory, explicit memory, and implicit memory. (1) From the sensory memory perspective, the system has different 3D views (the 1st person view and 3rd person view), background sound, and zoom features for users to choose. The user is represented by an avatar which mimic a human figure. The user can control the avatar to move around and interact with the supermarket environment. (2) To improve working memory, we designed shopping tasks for users to perform in the virtual supermarket. The tasks have five different difficulty levels based on the number of items that need to be purchased (easy: 3, simple: 5, medium: 7, difficult: 10, and extremely difficult: 12). Based on Miller (1956)'s law of the magical number seven, the medium level of difficulty is set to seven items. To complete a task, users need to be able to remember the listed grocery items in five different categories (fruit, meat, fowls and eggs, fishes, and vegetables) and find them at the right location. (3) To train users' explicit memory, each user needs to remember his/her assigned avatar which has specific appearance. They also need to remember the major VR components. (4) To enhance implicit memory, users are required to understand how to operate the VR system, including moving the avatar, adding items to the shopping cart, identifying/switching items, and other system functions.

VR-Supported Intervention

The VR system is designed to support interventions that help older people mitigate MCI. The intervention requires users to purchase grocery items in the virtual market based on a given shopping list.
The user first logs into the system. She/he is able to select an avatar, a viewing perspective, and background music. Then she/he is prompted to choose a difficulty level for the shopping task. A list of items need to be purchased for the task within a time limit. A score will be given based on the user's performance once the time limit is reached. The system also provides a ranking of users based on their past performance.

Evaluation of the VR system

We conducted a pilot test to evaluate the effectiveness of the VR system. We recruited 120 senior people from a large senior center in China. At the beginning of this study, two IT technicians went to the senior center and offered a two-day training on how to use the VR system. The participants were requested to use the VR system for 10 weeks. Before the intervention started (baseline), two nurses evaluated the participants' cognitive capabilities using the Montreal Cognitive Assessment scale (Nasreddine, et al, 2005). Right after the 10-week (post intervention), the participants' cognitive capabilities were reevaluated using the same scale. Each participant's system usage record (including system use time, difficulty level, avatar move distance, and mouse click time) during this 10-week period was recorded and saved in the system database. We also collected these senior people's demographic data and health status information as control variables. We are in the stage of data analysis. We hypothesize that there is a positive relationship between these senior people's system use and their cognitive capability change. We plan to present some preliminary data analysis results at the conference presentation.

Significance and Contribution

To the authors' knowledge, this is one of the first studies attempting to integrate memory theories with VR design to improve senior people's mild cognitive impairment problem. It can provide an excellent foundation to contribute to the growing body of DSR papers. By mapping between system features and memory types, we attempt to use the VR system to improve memory abilities in a holistic manner. This design approach helps researchers identify important system functions and avoid omission errors. We not only design and develop the VR system, but also test whether it can have impact on older people's memory capability. This study contributes to DSR by relying on design to answer real world meaningful questions. This study can have great practical value. If found effective, the VR system could become an easy-to-use, convenient, and inexpensive tool for older people to use on a regular basis. Before effective medications are discovered for MCI, it can play a prominent role in alleviating the MCI problem and improving people's wellbeing.

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