Towards a VR-based Cognitive Assessment and Rehabilitation Tool for Cognitively Impaired Elderly People

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ABSTRACT
With increased life expectancies and improved quality of life conditions, many people find themselves living long and healthy lives until they reach old age, when the body starts decaying, and the brain is no exception.

The primary objective of this paper is to introduce a novel approach on the evaluation, prevention and training of the elderly afflicted by cognitive disorders, within a virtual reality environment. By adapting and enhancing examinations normally used in the specialized medical field combined with the potential of virtual reality, a path to new possibilities opens up. The data gathered from various studies strongly suggests that mental exercise is a key factor in the prevention and alleviation of the evolution of dementia.

The aim of our system is not only to detect and mitigate early signs of dementia, but to offer a mentally stimulating VR-assisted activity for the elderly, an important step in the rehabilitation of the elderly and potentially a forward step in the research field of cognitive impairments.

Author Keywords
Virtual Reality; Cognitive; Assessment; Rehabilitation; Training; Dementia; Alzheimer's Disease; Elderly; Cognitively Impaired.

ACM Classification Keywords
H.5.m. Miscellaneous. H.5.1. Multimedia Information Systems. H.1.2. User/Machine Systems

General Terms
Human Factors; Design; Measurement.

INTRODUCTION
The process of aging is natural for any demographic, populations having increased life expectancies thanks to industrialization, modern medicine and an improved life style, which ultimately lead to lower death rates and longer lives. The global average lifespan since 1900 has been gradually increasing to approximately 70 years, which compared to previous centuries when the average was a fluctuation between 30 and 40 years, going as low as 23 years in India and South Korea [27], can be considered an objective improvement. Studies conducted in 2015 suggest that Japanese women may have the longest average lifespans with 86.8 years, while on the opposite end of the spectrum, people from Sierra Leone would have a life expectancy of approximately 50 years [32].

Despite the successes of health care and the improvements they have brought, afflictions started appearing in the increasing demographic of old people. Cancerous, respiratory and circulatory diseases are some of the leading causes of death, but mental conditions are on the rise, dementia already becoming the most deadly affliction for Australian women [29], and at the rate it is evolving, forecasts suggest that there will be 131.5 million people suffering of dementia in 2050, from which 68% will be from low to middle income countries [21].

The main objective of this paper is to propose an enhanced version of the general assessment methods for cognitive disorders like dementia, or at the very least an auxiliary tool to be used in certain situations, as well as a system for training, monitoring and rehabilitation for cognitive-impaired elderly people through virtual reality headset-based applications.

Our contribution starts with the state of the art in the dementia field. Next we present the research method together with some preliminary results. We conclude with discussion and future work.

BACKGROUND
Researchers suggest that in many situations (20-50% in high income cases, 90% in India) dementia isn't properly diagnosed or remains completely undiagnosed. With over 9.9 million new cases discovered worldwide on a yearly basis [21], performing an early diagnosis and intervention can make all the difference [22].

Dementia's most common form (at about 60-80% of cases) is Alzheimer's disease, a fatal disorder which progressively affects the brain functions, killing brain cells, causing memory loss and behavioral changes [24]. Once the signs of the disease are noteworthy, patients start losing their conversational abilities, failing to respond to environmental stimuli, struggling with everyday activities, ultimately leading to a slow death in a range of 4 to 20 years, based on age and other various health factors. [24]

There is no known treatment that would cure or entirely prevent Alzheimer's disease from escalating, but ways of mitigating its effects have been found and are continually being developed. Both drug- and non-drug-based methods may assist with the alleviation of the symptoms, slowing down their evolution and enhancing the life quality of the patient (and the caregiver, if any). [20]

The therapeutic benefits of counseling performed by a psychiatrist and/or a geriatrician can be evident, especially via testing methods to evaluate the evolution and gravity of the illness. The examination can slightly vary from one practitioner to another, based on region, individual methodology or the standards set by the local social services for the elderly.

Studies suggest that socially and mentally active individuals have lower risks of being affected by Alzheimer's symptoms due to stronger neuronal synapses. [23] In the same manner, several studies claim that cognitive training for older adults with mild cognitive impairments may have long term effects of improving their overall mental state, as well as in some severe cases showing some improvements [17, 12, 10].

Our motivation comes from living with two elders with cognitive problems for several years and observing their behavior; thus we have always strived to be mindful of their health conditions, challenging their afflictions through various mental, social and emotional activities, in order to help them to live long and comfortable lives.

The involvement of technology in such activities has proven to be efficient, offering various new prospects for supporting the elderly through the intervention of the digital mediums and methods in their training. [5, 3, 1, 15] Virtual reality could be a step forward in this direction. [14, 9]

RESEARCH METHOD

Our goal is to adapt a form of Mini-Mental State Examination (MMSE) [2] to a virtual environment, combining various forms of testing with an accessible and user-friendly application, which will not just give a general idea of the mental state of the user, but will also offer an engaging activity that will stimulate the mind and spirit. In certain forms, it can also become a recreational activity, offering gratification to a certain extent.

The target priorities we are aiming for are the following:

- Orientation
- Memorization
- Attention
- Information Reproduction
- Comprehension
- Complex Tasks

Methods of Evaluation

While the classic pen and paper methods are still successfully being used in most domains, the interactive tablet or personal computer (PC) methods are slowly joining in, but the prospect of implementing virtual reality (VR) should not be too far in the future.

A classic MMSE, also known as a Folstein test, is normally used for measuring the severity and progression of a cognitive impairment [4, 26]. With both advantages and disadvantages, this questionnaire is broadly and extensively being used across clinical and research areas that cover dementia and other cognitive-related afflictions [28]. Adapting it to the VR medium might prove beneficial in certain aspects, but difficult in others.

Priority	VR Translation
Orientation (in space/time)	Comprehending and performing basic head movement commands Recognizing/remembering temporal symbols
Memorization	Observing and remembering certain objects placed in the environment
Attention	Choosing the odd model out of multiple identical ones
Information Reproduction	Remembering and selecting the previously used objects
Comprehension	Understanding the different scenarios and acting accordingly
Complex Tasks	A combination of the previous steps

Table 1: Evaluation priorities with their potential VR implementation

EXPERIMENTAL SETUP

The ideal conditions, which might not always be met due to the various degrees of degradation affecting the cognitive functions of the individuals, would require the patient's cooperation, a formal caregiver who would set up the device and oversee the process, as well as offer any assistance where it is needed.

VR Setup

Figure 2: Setting up the VR head mount on the elderly

In the progression of technology, large steps have been taken in the past decade, making most devices affordable to the consumer public. While the dedicated VR devices are still being developed, the prices remain fairly high, requiring powerful PCs and rigorous setups. The useful and accessible alternative would be an average or better smartphone (mobile phone with touch screen) combined with a head mount on which the application can be developed. Another visible advantage would be the portability offered by the mobile device, as noticed in Figure 1, which can be used in both clinical and domestic environments with ease.

3D Setup

The development tool used for this application is Unreal Engine, an accessible tool with an extensive amount of features. One of these features is the native integration for most of the popular platforms when building VR applications, offering a robust and varied development environment, maintaining acceptable quality without compromising performance. [30, 31]

Interaction scenarios

Once everything is set in place and the conditions are met, the graded examination can begin.

Step 1: Calibration and Adjustment

The initial phase begins with the testing of the main interaction method, looking around and discerning the surrounding. The patient will be tasked with tracking a red ball, like the one in Figure 2, on a predetermined route and focus on it while it is placed in certain fixed locations around the general vision field.

The purpose of this step is to help determine the general awareness and attention span levels of the patient, as well as to factor in the general mobility of the head, angles it can manage to cover and the reaction times.

While it can be considered a warm-up phase, it is a vital part in the introduction of the application, assessing the reflexes needed for the following steps.

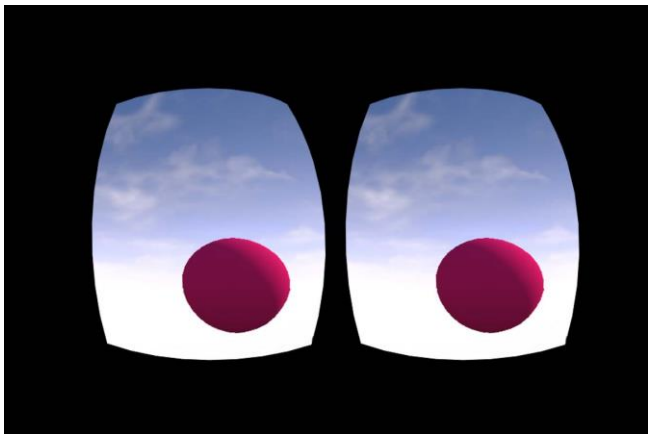

Figure 2: VR perspective of the calibration phase

Step 2: Orientation Test

The second phase will task the patient with demonstrating both spatial and temporal recognition capabilities, through following simple directions, remembering the current date and their present location.

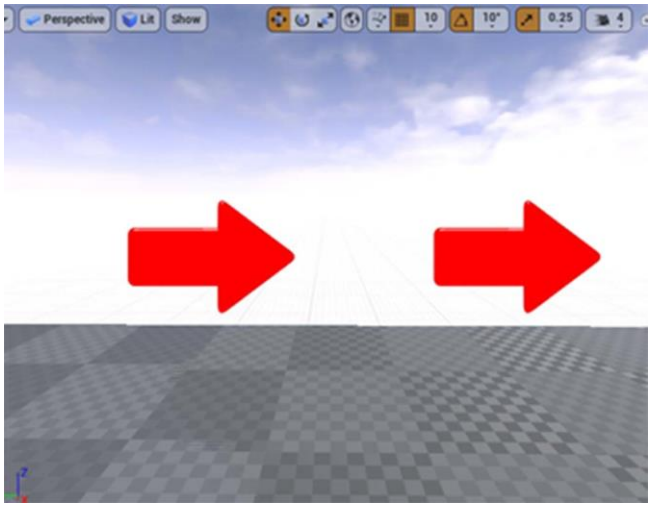

Figure 3: Setting directional markers for the orientation phase

Step 3: Memorization Test

The memory test will help to establish the capacity of the patient to record and recall 3 basic shapes and colors, as well as other common known objects or animals in a particular order. We can observe a basic example in Figure 4.

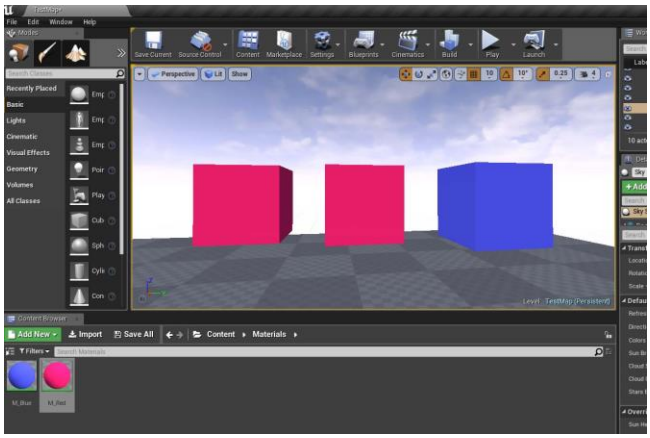

Figure 4: Designing the memorization tests in the Unreal engine

This phase is useful for the verification of the patient's short-term memory, which will be further tested in a future step, as a callback to this sequence.

Step 4: Attention Test

The fourth part tests the attention of the patient, requiring a certain degree of concentration for identifying an object among others, usually hidden in plain sight, but still challenging the participant at inspecting his surrounding until finding the sought object.

Step 5: Information Reproduction

This step directly ties with the previously mentioned short term memorization part, which will require the participant to recall and recreate the sequence used before.

Step 6: Comprehension

The sixth step will check the patient's reasoning and comprehension abilities, being asked to discern certain objects or do certain tasks, mainly using visual and text prompts, as well as audio requests.

Step 7: Complex Tasks

This final step can help determine with better accuracy the severity of the cognitive impairment of the participant, combining previous steps in a command string with multiple stages, which will be accomplished in the VR medium.

Final Part

Once all the steps are completed, the data gathered is aggregated and the results will be displayed and stored. Based on the score obtained in the evaluation, using the recommended reference table, the severity level of the cognitive dysfunction can be deduced.

By following this routine, we can get a general idea of the patient's mental state. Variations with added, altered or removed steps could be designed in the future, based on the data and feedback gathered.

Score	State
>=21	Lightly affected or still in early stages
10-20	Moderately affected, with some noticeable signs
<=9	Severely Affected

Table 2: Recommended references for the evaluation of cognitive disorders.

DISCUSSIONS

The elderly, aged at 65 and older, are the world's fastest growing population [33], representing nearly 9% of people worldwide, estimated to reach 17% in 2050 [36]. They have been through many changes across these decades and it would be understandable for them to feel anxious about trying something new. But this anxiety can be conquered by one of the strongest human instincts: curiosity. Introducing the elderly to the virtual environment (VE) can be uncomplicated through the use of familiar or nostalgic images and experience in the VR [38]. The interest in VR methods is on the rise [35].

While a VR version of a MMSE test can bring many improvements to the paper version, its adaptation can have several drawbacks as well, due to current limitations. Some parts of such a test may involve drawing, writing or speaking. These are actions that would normally require the involvement of another human, who would interpret them accordingly. It is something which VR on its own might not be yet prepared to handle very smoothly, at least not without aid. In theory, this could be solved by introducing a tablet and a microphone, programmed in such a way to detect and recognize the input of the patient, but reliability can be questionable at this point of time. A compromise would be combining the classic methods with the new ones, until further progress has been made.

Advantages and Disadvantages

The prolonged use of the VR device may cause a form of motion sickness to some participants, also known as *cybersickness* [8]. This can potentially have a negative impact on the overall experience of the patient, especially due to their old age and possible health problems [7], despite their reduced susceptibility to motion sickness [6]. Luckily, large steps are being taken to remediate such adverse effects, with upcoming new technology and methods [34]. Some helpful ways to minimize such effects would be to have a segmented experience, with breaks in between, and slowly building tolerance [37]. Using a stationary position with no sudden movements in the surroundings is also a beneficial way of avoiding sickness in our case.

While the application would be made intuitive, using easy to understand and basic commands, combining visual and audio stimuli, it can still be proven difficult for people in advanced stages of dementia, in which the visual and/or auditory acuity is highly diminished, making the interaction with the examination troublesome. While blindness or deafness can be considered solid obstacles for examining, in the later stages of cognitive disorders, patients can become unreasonable or nearly impossible to interact with.

Since the constitution of elders can be frail, many of them might find themselves, willing or not, in sedentary states with limited physical capabilities, some even being bedridden. The VR headset can aid those in such states, not only for the cognitive issues, but for the rehabilitation of disabilities as well, in both lower and upper extremities. [19, 13, 11]

CONCLUSION AND FUTURE WORK

In this paper we have designed and developed a tool that can be used for both assessment and rehabilitation, to a certain degree, of cognitive functions, focusing mainly on dementia. While some similar methods already exist in certain forms, the novel approach of adapting and enhancing them to the VR medium, which has proven effective in other fields, can only bring benefits and leave a lot of space for further research in this area.

In its current adapted conceptual form, the application meets some preliminary requirements, sharing most of the advantages and disadvantages of a regular MMSE, but compensating with its intuitive visual environment and intuitive controls. It can be further improved with the addition of a VR controller, which could vastly expand the motion capabilities. Strong headphones can also be useful, for those auditorily impaired, and would allow broader alternatives to experiment with audio methods. An online component could help with storing the data to the cloud and achieving a form of convenient remote assistance for the patients using it.

While the main purpose is to diagnose and track the severity of a cognitive affliction, focusing more on the training and rehabilitation part can be equally beneficial. This can be done through adding more challenging, recreational and relaxation activities in the VR environment, which would stimulate the mind of the patient, slowing down the degradation process. Studies and medical practitioners agree that mental exercise is one of the key factors. [25, 16, 18]

We acknowledge that tests in this study were done in a small number due to time constraints and liability concerns, deeming the gathered results as irrelevant and not including them. Future work could include larger groups of participants who will provide essential data for further development in this field.

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