Augmented Reality for Early Alzheimer's Disease Diagnosis

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ABSTRACT

Alzheimer's disease (AD), the most common type of dementia, is characterised by gradual memory loss. There is an increasing global research effort into strategies for early clinic-based diagnosis at the stage where patients present with mild memory problems. Initiating treatment at this stage would slow the progression of the condition and enable more years of good quality life. This paper presents the ongoing development of an augmented reality system using HoloLens that is designed to test an early onset of Alzheimer's disease. The most important aspects in the early AD diagnostics are the symptoms that appear to be connected with early memory loss, in particular spatial memory. The ability to store and retrieve the memory of a particular event involving an association between items such as the place and the object properties is incorporated in a game environment.

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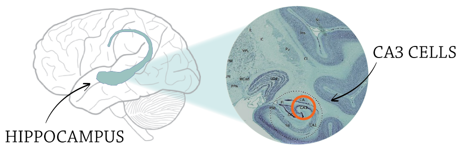

Figure 1: The hippocampus serves as the neural substrate for allocentric (viewpoint-dependent) cognitive mapping of a person's environment.

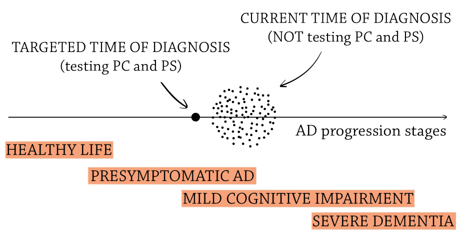

Figure 2: Alzheimer's disease progression stages and time of diagnosis.

KEYWORDS

Augmented Reality; Mixed Reality; HoloLens; Alzheimer's; Memory;

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INTRODUCTION AND MOTIVATION

On average, 1 in 11 people over the age of 65 is now living with dementia. As the average life expectancy increases, the prevalence is forecasted to double every 10 years [7] in the developed world. There are over 100 forms of dementia and the most well-known is Alzheimer's disease, which accounts for 50-60% cases [12]. Alzheimer's disease is characterised by gradual memory loss caused by a preferential loss of brain tissue in the hippocampus, the part of the brain responsible for encoding spatial memories [4] (see Figure 1). Damage to this brain region has been shown to impair spatial problem solving, including the acquisition of novel routes and navigation in familiar environments [5]. However, clinic-based diagnosis of AD is often made very late in the natural history of the condition, after severe memory impairment has taken effect (see Figure 2). Early Alzheimer's disease symptoms are similar to the changes that are part of normal age-related cognitive decline. That is why the early detection of AD in clinical environment is very difficult [11]. In this view, there is an increasing global research effort into strategies for early (clinic-based) diagnosis at the stage when patients present with mild memory problems. Initiating treatment at this stage would slow the progression of the condition and extend good-quality life span [8].

Established present computer- and paper-based clinic tests are unable to assess spatial memory in a biologically-plausible and unbiased way (real-world settings). These tests are instead heavily skewed towards verbal competencies, which patients with Alzheimer's disease are tend to perform well on, thus providing a false sense of reassurance [9]. Augmented reality can circumvent these methodological drawbacks by blending real-world objects in clinic with controllable virtual testing and diagnostic instruments.

There is a great interest in how technological advancements in augmented reality can be implemented in everyday life. The potential advantages of such systems seem almost limitless and appeal to both academic research and data-driven healthcare. In this study we explore the use of the HoloLens technology as a new ecologically valid tool for early Alzheimer's Disease diagnosis.

We use the Microsoft HoloLens to build an augmented reality spatial memory cognitive game environment to test 'pattern separation' and 'pattern completion', two hippocampal functions with a strong neurobiological basis as part of the (CA3) pathway encoding (spatial) episodic memories (see

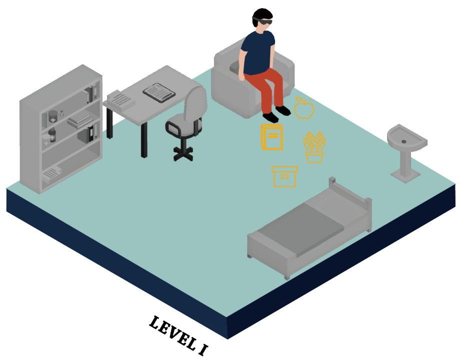

Figure 3: Illustration of the Level 1. Introduction to the game environment (mock-up of the real room in the Addenbrooke's Memory Clinic in Cambridge, UK).

Figure 4: Illustration of the Level 2.1. Here the user will see the object selection for the first time.

Figure 1). Impairment in the ability to perform pattern separation and completion tasks occurs early in the natural history of Alzheimer's disease, and as such, the ability to test these functions reliably would facilitate early diagnosis and treatment.

In the following sections, we describe the problem further, explain why existing methods are not capable of diagnosing early AD, propose new AR-based spatial method, and discuss future work.

EXISTING METHODS

The most important aspect in early AD diagnostics is the focus on symptoms that appear to be connected with early memory loss, in particular spatial dysfunction [14]. It is known to be one of the strongest factors that impact individual differences in cognitive abilities. In particular individuals suffering from early AD have significantly impaired spatial memory capacities that worsen as the disease progresses. Spatial memory is the part of the human memory responsible for recording geometric relations involving observers, objects and surfaces, as well as the information about location, orientation, and direction [1].

The main modern diagnostic tools used by clinicians are based on the usage of written tests to anticipate the decline of cognitive symptoms (tests such as MMSE [15], ACE-R [10], CAMCOG [6], IOCODE, VPT [9]). However, in terms of assessing the existence and functionality of spatial memory these tests rely heavily on verbal competence and are not always appropriate for subjects with early AD, who are more likely to perform well on these tests. Since spatial memory performance decreases with the progression of AD, it is highly important to create an ecologically valid tool that would assess brain performance. To our knowledge, augmented reality work in a field of AD is limited, with only one study looking at the HoloLens as a therapeutic tool for people with the Alzheimer's disease [2], and no attempts to utilise augmented reality as a diagnostic instrument.

ECOLOGICALLY VALID TEST

In the real world, people have a physical presence in their spatial environment, surrounded by objects and landscape. Clues that are embedded in the natural and build environment facilitate our sense of orientation and spatial understanding, for instance, a door gives a sense of directional information [1]. As people move about the environment, they acquire knowledge about patterns of spatial relations among places and properties of the objects in the world. This knowledge is encoded and stored in memory, allowing people to find the places again.

In the context of emerging interaction styles, augmented reality is one of the main mediums through which we can acquire spatial knowledge at environmental scales, insofar as it affords apprehension of the most precise information at the different distances. AR environments are interactive and respond to locomotion or other motor behaviour of the user and tend to mimic real life static and dynamic spatial patterns. To illustrate the ecological significance of object-location memory assessment tests we think that augmented reality environments have the potential to encompass all of the aspects that are required to test for early spatial memory loss and point towards early Alzheimer's disease or other disorders. Additionally, we have involved clinician in the design process of this system to make it valid and useful.

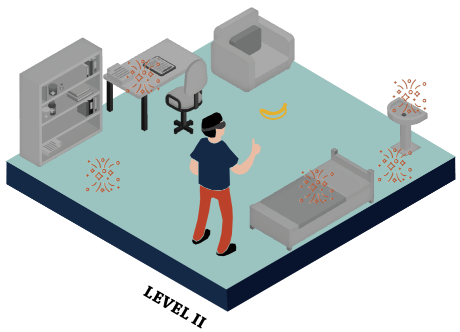

Figure 5: Illustration of the Level 2.2. This level is designed to test pattern separation function.

Figure 6: Illustration of the Level 2.3. This level is designed to test pattern completion function.

NEUROBIOLOGICAL BASIS AND GAME DESIGN RATIONALE

The hippocampus serves as the neural substrate for allocentric (viewpoint-dependent) cognitive mapping of a person's environment [1]. Damage to this brain region has been shown to impair spatial problem solving, including the acquisition of novel routes and navigation in familiar environments [14]. Some of the relevant evidence about the functions of the hippocampus in spatial memory comes from the effects of damage of hippocampus. Patients who are potentially impaired and have problems with the hippocampus would not have the ability to remember feature of novel environments, such as the spatial layout and episodes that took place during the exploration.

The fact that spatial patterns, which imply continuous representation of space, are represented in hippocampus has led to the appreciation of hippocampal functions. These functions involve *pattern completion* and *pattern separation*, which enable rapid associations between any spatial location and an object. **Pattern completion** fills missing gaps of the recent events (by comparing patterns) and helps us understand that the scene we experienced before has not changed [13]. For example, comparing the desk setup after you return back from the short brake and confirming that everything is on the same place as it was before. **Pattern separation** is the ability to discriminate among similar experiences [3]. For instance, comparing the desk setup when you return back after the short break and realising that the cup on the desk in missing. Some have argued that pattern separation is the hallmark feature of spatial memory [5], meaning that if we can test it, that would definitely point towards potential performance deterioration and environmental awareness.

Visual environmental scenes contain distinct features that somehow have to be grouped together in coherent units. One of the most important features is location. People do not only need to know which locations are relevant, but often also have to remember which other features - for example, shape or colour - correspond to those locations. Knowing 'what is where' essentially concerns the question of how features are bound together in memory. Impaired spatial memory affects the ability to remember where things are, in particular processing object-to-location and objects-to-object associations, and points towards the early Alzheimer's disease. Specifically, these behaviours would comprise searching for and finding tools, keys, and so forth in the environment. These neurological principles form the basis of our spatial game environment for creating AR based diagnostic instrument.

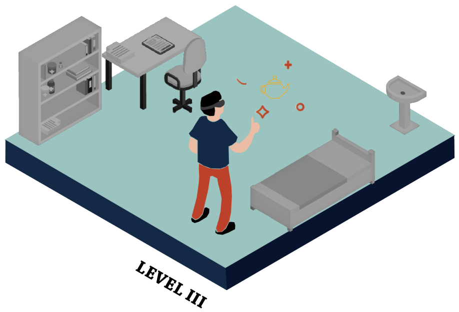

Figure 7: Illustration of the Level 3. This level is designed to test pattern recognition function.

PROPOSED METHOD AND GAME DESIGN

To address the problems faced by current diagnostic methods, we propose to use real world environment and augmented reality as an ecologically valid spatial memory assessment tool. This tool will be used in clinical environment to compliment existing memory assessment tests as part of the early AD diagnosis. The designed AR game is focused on the fundamental property of spatial memory - the ability to store and retrieve the memory of a particular singular event involving an association between items, such as the place and the object properties. The game environment has three levels, each dedicated to testing a specific hippocampal function mentioned above.

- **Level 1** aims to introduce the user to the HoloLens and invite to explore the game environment. The user is sitting in a chair and is introduced to the HoloLens by a clinician for the first time. The user practices air tapping to place holograms around the room (see Figure 3).
- **Level 2.1** aims to test user's ability to recognise 'unnatural' placement of objects. The user is asked to 'destroy' virtual objects that are intentionally misplaced (e.g. lamp in a sink) by air tapping on them (see Figure 4). This task will familiarise the user with the object selection for the first time.
- **Level 2.2** aims to test pattern separation. The user is asked to air tap on the holographic object (cloud) where they think the hidden object was originally placed (see Figure 5).
- **Level 2.3** aims to test pattern completion. User is asked to airtap on the holographic objects that have changed their appearance (e.g. virtual towel now is blue, but it was white) (see Figure 6).
- **Level 3** aims to test pattern recognition (PR). The user is asked to find parts of an object that can be assembled together from a number of distinct elements (see Figure 7). PR is an additional memory function that is tested as part of classical memory test in clinic, but in AR it can be experiences in 3D.

DISCUSSION AND FUTURE WORK

While existing computer- and paper-based tests are unable to test spatial memory in a plausible way, they are presented to the users from targeted age groups in an interaction medium familiar to them. This means that a new paradigm of spatial computing could act as a cognitive barrier to the user. This requires further investigation and a carefully planned experiment with the patients (both healthy subjects and MCI (mild cognitive impairment) patients). Formal evaluation comparing this work with other modern diagnostic tools is required in the future as well. From the design point of view it would be interesting to explore the adaptiveness of the AR content to different room setups. One of the features of the proposed tool is that the correct meaning of the virtual game content derives only when it is located in the physical room (i.e. digital lamp in the physical sink is incorrect, but digital keys on the physical desk is correct). Additionally, this study could bring insight on how adults and elderly people perceive and interact with augmented reality in general (both clinicians and patients). At the current stage, the application is ready to be tested in clinical environment. The user study is planned for the evaluation phase of this project where we want to observe how the users will interact with a holographic device. Future developments will validate the system and evaluate its ability to assess the targeted medical condition.

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