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Augmented Reality cube game for cognitive training: an interaction study

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Abstract. There is the potential that cognitive activity may delay cognitive decline in people with mild cognitive impairment. Games provide both cognitive challenge and motivation for repeated use, a prerequisite for long lasting effect. Recent advances in technology introduce several new interaction methods, potentially leading to more efficient, personalised cognitive gaming experiences. In this paper we present an Augmented Reality (AR) cognitive training game, utilising cubes as input tools, and we test the cube interaction with a pilot study. The results of the study revealed the marker occlusion problem and that novice AR users can adjust to the developed AR environment after a small number of sessions.

Keywords. Augmented reality, cognitive training, cubes, interaction

Introduction

Cognitive decline is associated with risk for functional decline, nursing home placement, depression, anxiety and mortality, especially in older individuals [1]. Interventions that reliably improve cognitive function thus have the opportunity to substantially improve the health and quality of life of the elderly [1].

Studies in animals and humans suggest that non-specific cognitive stimulation reduces the risk of cognitive decline. This has led to the practice of encouraging older adults to engage in everyday cognitively stimulating activities [1]. Even though, the retrospective and observational designs of the human studies have led to difficulty interpreting the direction of causation between cognitive function and cognitively stimulating activities, studies around the utilisation of video games for cognitive training (e.g. Lumosity, Posit Science, et al.), have produced positive indications for significant benefits on affecting memory function, attention abilities, emotional state, and, in general, improving executive functions and slowing down cognitive decline [2].

However, present cognitive game platforms and software, as well as the studies that accompany them, focus mainly and directly on the "serious" aspects, i.e. the stimulation of the targeted cognitive functions, at the expense of the game design and the interaction technique can have on the user experience, thus on the players' emotional response and on the targeted cognitive functions. The majority of the cognitive games are designed for desktop PCs, gaming consoles or mobile devices (smartphones and tablets) utilising keyboard/mouse, controllers or tapping as the main input methods, using screen monitors as output devices [2,3]. Recent advances in technology (e.g. gestures/hand tracking, augmented reality [3]., biosensors, high-

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fidelity virtual reality et al.) allow us to have several new interaction methods at our disposal, in order to explore the design of more robust and efficient, personalised cognitive training experiences.

Designing engaging cognitive video games, addressing the motor skills and the emotional state of the players, as well as getting secondary data, supplementary to the cognitive performance (e.g. stability of hand movements, heart rate, breathing activity et al.) are potentially feasible goals that may lead to the next generation of cognitive training and assessment software. To move in that direction, we have designed a *cognitive Augmented Reality (AR) cube* system. The cognitive AR cube system is an AR cognitive training game, utilising cubes as input tools. The game is of preventative nature and is targeting, primarily, mild cognitive impaired players, players at the initial stages of mild dementia, and secondarily healthy adults. The ultimate goal of the cognitive AR cube system is to alleviate cognitive decline and to provide timely cognitive assessment information to the player, thus playing an intermediary role between the (potential) patient and the medical expert. The final product is destined to be a collection of 6 cube mini-games, though during the first step we are studying the interaction with the cubes and Augmented Reality implementing the prototypes of 2 core cube mini-games. The interaction goal is to provide the players with a cognitively stimulating interaction technique (use of cubes, AR et al.), which will utilise known interaction metaphors, will be portable and will be used without the help of experts/professionals.

In the following, we describe the followed development process (Section 1), analysing the components and the interaction design of the system (Section 2-3), and concluding with an interaction pilot study (Section 4).

1. Developing the cognitive AR cube system

In this study, the first stage of the project is analysed by examining the interaction technique of the AR cube system (grey highlighted box in Fig. 1) - utilising AR and cubes - with a pilot study of random participants with unknown cognitive status.
However, this study stands as an important first step in the whole development process of the system. For the development of the cognitive AR cube system, we follow a rigorous design process in three parts: examining interaction, solve technical issues, and testing the game's effect on player's cognition (Fig. 1).

The prototyping process is broken down into two parts: the low fidelity prototyping stage and the high fidelity one. The main reason behind this distinction is to utilise the low fidelity prototype to solve the main interaction and technical issues, as experienced and suggested by a generic sample of players with unknown cognitive status. Then, the suggested changes are applied and the produced high fidelity prototype will be tested on the main target group (mild cognitive impaired or players with mild dementia), in order to recognise and highlight the unique interaction requirements of the group, if any. Naturally, each development stage described herein includes several iterative design processes until ensuring the proper system quality that will allow moving further, to the next stage. The ultimate goal of the presented design process is, in the end, to produce a robust cognitive training system that will provide us with objective cognitive perfomance-related results, which will be directly affected by the mini-games of the system and which will not reflect interaction or technical inadequacies.

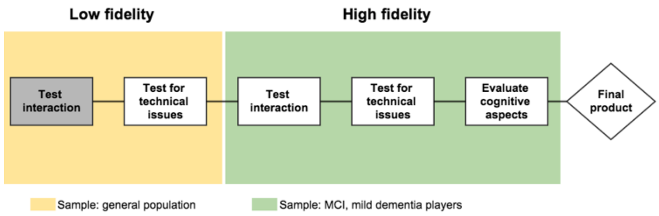

Figure 1. The flowchart of the cognitive AR cube system development process.

2. Designing the interaction of the cognitive AR cube system

The use of physical objects as tools for cognitive training and assessment is well established, especially for the assessment of constructional and matching abilities, which integrate perception and motor response in a spatial context [4].

Cubes are an accredited assistive tool for occupational therapy [5], further used in a wide range of tasks, like cognitive training [6,7], cognitive assessment [4], motor rehabilitation [7], neurodevelopmental treatment [8] and social engagement through multiplayer gaming [6]. The game element that is associated with the cube, usually originating from childhood memories, transforms them into playful, entertaining objects, appealing to a wide target audience - ranging from children to elderly players - with various health profiles [6,9,10].

Consequently, we consider the cube to be not only an ideal input mechanism for cognitive training, but also an assistive tool that can help address the physical/motor skills of the player, thus collecting significant data for the health benefit of the player.

The cubes, also, provide a promising platform for augmentation with various gaming "skins", as shown in some of the aforementioned works and projects, providing us the opportunity to explore the area of Augmented Reality further.

Augmented Reality can be beneficial for mental processes, supporting spatial cognition and mental transformation [3]. Furthermore, it may reduce cognitive load by minimising attention switching, promoting continuous use and physical movement [3].

Especially, in games, AR can evoke the initial engagement of the player utilising the "wow effect", coming from the visualisation of an alternative "reality", augmented with 3D artifacts. Even though, the "wow effect" is short-lasting, it provides the kick-start for engaging the users into playing the game, causing a strong initial impact by addressing to the players' visceral level of processing, which may potentially influence the overall gaming and training experience [11]. Finally, the fact that AR utilises a variety of sensors (e.g. camera, accelerometer, magnetic compass et al.) allows us to get valuable secondary data about the movements of the players, thus being able to assess the players' physical performance and evaluate the changes over time.

3. Designing the cognitive AR cube system

The interaction technique implemented in the described first stage features the player sitting in an office, playing the game on a tablet PC by manipulating AR cubes, that are placed on the actual desktop. The cognitive training can take place in a small space, while the whole system is quite portable; it consists of 9 cubes of 3,5 cm/edge, a tablet PC and a base stand (Fig. 2).

The design requirements suggested that the player should be able to use both his/her hands in order to manipulate the cubes. AR glasses would be an ideal solution, however - so far - the available options are at an early development stage. In this study, we implement the “magnifying glass” metaphor: an adjustable arm desktop base stand supporting a tablet PC (our version of “magnifying glass”) which the player can adjust according to his/her position, in order to have clear view of the desktop, where he/she will interact with the cubes using both hands (Fig. 2).

In order to test the interaction technique, we developed the prototypes of two core mini-games. Those games were chosen because they implemented two different gaming and interaction styles, that would allow us to witness the player's performance under two different conditions. The first game is a *word game*, which trains logical reasoning. In the game, the player uses 9 letters (displayed as 3D models on the cubes) to form as many words as possible within 5 minutes. The second game is a *speed/shape-matching game*, which trains response inhibition and information processing. The player should match simple shapes (cube, sphere et al.) of different colours as quickly as possible. The first game favours a more focused and calm interaction, whereas the second game favours fast movements. Each game had 4 levels. The 3D objects of the games were designed in a minimal way with plain textures.

Figure 2. The cubes (left), the player's game view (middle) and playing during the pilot study (right).

For the development of the low fidelity prototype, the Android Vuforia AR SDK was used, and as a testing device we used a tablet PC with a moderate-sized screen and a high-resolution camera (Sony Xperia Z 10”).

4. Studying the interaction of the cognitive AR cube system

A pilot study was conducted in order to study the interaction with the AR cubes, as well as with the “magnifying glass” base stand. The study was exploratory in nature, looking for interaction problems and specific user behaviours and it was based on direct observation of the player's movements by two AR experts and a semi-structured, informal interview at the end of each gaming session. A random sampling technique was used, in order to register five participants. The participants were asked to game-test the two AR games of the system, to minimise the experimenters' effect on them when interacting with the system. The categorisation of the players was based on their previous experience on using Augmented Reality applications. Two experienced AR users, one moderate AR user and two novice users participated in our pilot study.

The participants had 4 sessions of playing the two games, within a week. Each session consisted of a different level of both games and lasted approximately 10 minutes. At the beginning of the first session the game scenarios were given to the player and at the end of each session a semi-structured interview was conducted, asking for the player's feedback on the cubes interaction, the AR technology, as well as the game setting. The results of the study show us the benefits and the problems of the selected input/output methods.

4.1. Results

All 5 players completed the sessions with minor interaction complaints. The experienced players mastered the games and the AR cube interaction right away (Fig. 3). However, their style in the word game was featuring fast and sudden movements, that led to the constant reproduction of the marker occlusion problem, i.e. the players used to grab the cube in a way that their hand obstructs the tracking of the marker, therefore the 3D model that was "linked" with the marker was not displayed, until the marker was visible again. They both highlighted the *marker occlusion problem* (although admitting they sometimes caused the problem in order to save gaming time) and one of them highlighted a common AR interaction issue, that of *lagging*, i.e. the delay (in milliseconds) between the real movement of the player's hand and its display on the screen via the AR camera capture. In general, the experienced users were more focused on playing the game and completing the task, than mastering the interaction technique. Specifically, after the first session both users mastered the system, accomplishing high scores. The players did not face problems with the "magnifying glass" metaphor, adjusting the AR view through the tablet, according to their postures.

The moderately experienced player faced the *occlusion problem*, however she managed to overcome it the fourth time it appeared (the experimenters did not provide any help about the cause of the problem to the player) by picking the cubes from their sides. The player stressed the *small screen size (10 inches), which limits the 3D gaming space*. However, after the first session, the player had mastered the system, by being able to use the 3D gaming space as defined - and limited - by the AR camera view and by being able to quickly move the cubes, picking them correctly without obscuring the display of the 3D models.

The novice users were the main focus of our study, since the players of this category were completely unaware of the AR technology, therefore a different level of objectivity can be introduced to the results of the pilot study. Both participants experienced the "wow effect" in a degree. During the first session, one of them was moving carefully and slowly, try not to affect the 3D models that were displayed on top of the cubes. The other player found it difficult to adjust to the *depth perception* when looking through the tablet screen. The former player, also, stressed that "*in the word game it was difficult and tiring to reach out the cubes*", since he avoided to adjust the arm stand and the tablet AR view to his posture and he also *found the 3D gaming space, as defined by the AR camera view, to be limited*. The main finding related to the novice participants was that by the third session they managed to master the interaction and focus on the game, gaining high scores, get used to the depth perception and the AR view, ultimately resembling the gaming style of the other two user groups at the same session (Fig. 3). The *occlusion problem* was present in every session of the players (more intense during the first session), however after the third session they were aware of the problem and they were picking the cubes properly.

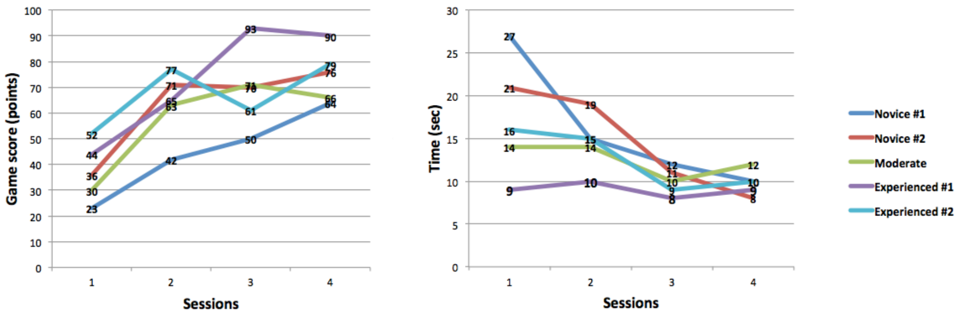

Figure 3. The players' performance (the players are categorised according to their AR experience) on the word game, measured by the game score (*left graph*) and on the speed/shape-matching game, measured in seconds needed to complete the level (rig*ht graph*).

5. Conclusions & future work

The main finding of the study was the *marker occlusion problem*, while we verified several AR technology-related limitations like AR lagging, losing depth perception, and dealing with limited 3D AR space. Another important finding was the fast adjustment of the AR novice users to the introduced interaction technique. So far, there are positive indications that AR cubes, combined with the "magnifying glass" interface metaphor, can be used for cognitive training games, however there are many technical issues to be dealt with, the occlusion problem being the major one.

In our future work, we plan to address the occlusion problem and tweak, in the degree, which is possible, the aforementioned AR limitations. Furthermore, the full set of games, even in a prototype shape, will be developed, in order to evaluate interaction with longer sessions, ideally lasting about 30 minutes. Our future goal is to complete the "low fidelity" stage, as described in Fig. 1, and test a robust, high fidelity prototype on our target group (cognitive impaired players), also examining the feasibility of the independent use of the system by the players (without external assistance).

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