A Tablet-Based Game Tool for Cognition Training of Seniors with Mild Cognitive Impairment

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Abstract. The purpose of this study is to examine the acceptability and effectiveness of a cognitive training game application targeting elderly adults with Mild Cognitive Impairment. Such kind of impairment signifies one of the earliest stages of dementia and Alzheimer diseases. Ten serious games were designed and developed in the Android platform to train cognitive functions such as Attention, Visual Memory, Observation, Acoustic Memory, Language, Calculations, Orientation and Sensory Awareness. In particular this paper examines the feasibility of playing such games with the participation of a group of seniors (N = 6) in a pilot study. Usability assessment was also performed by collecting qualitative and quantitative data. Another dimension that investigated was the possibility of using this game tool as an alternative to traditional methods for evaluating cognitive functions. The results show that participants could learn quickly and understand the game mechanics. They also found the games easy to use and showed high enjoyment.

Keywords: Healthcare · Serious games · Elderly · Mild cognitive impairment · User experience

1 Introduction

As our society tends to age, new needs and problems emerge both at the individual and at the socio-economic level. Therefore, a significant part of the research is now focused on improving the quality of life for the elderly people [1]. In this light, one area that is of particular interest to scholars is the maintenance of a satisfactory level of cognitive function, which tends to decline progressively with age [2]. Cognitive impairment in the elderly is a major social issue as it is associated with reduced independence, well-being and an increased need for caregivers [3]. Researchers agree that normal aging is accompanied by functional impairment in many different areas of perception, reasoning and memory. However, despite the fact that various theories have been proposed to interpret the mechanisms responsible for this reduction, its exact causes have not yet been clarified.

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A number of studies have focused on the effectiveness of cognitive empowerment in healthy older adults, but the collected data are unclear. Cognitive intervention appears to be effective in both improving the cognitive function of healthy older adults [4] as well as limiting the cognitive impairment seen in the elderly with dementia [5]. However, in surveys conducted to improve memory through cognitive training, only half reported a statistically significant improvement with the rest not exceeding the control group [6]. These data highlight the need for more research in the field of cognitive training.

On the other hand, Mild Cognitive Impairment (MCI) is considered as the transition stage between the normal senility and Alzheimer's disease (AD). It is characterized by impaired cognitive functions to a greater level than expected for a specific age, without meeting the criteria, in order to diagnose dementia, putting the patient, however, in danger for future worsening in terms of AD [7].

Until now, handwritten methods have been mainly used to identify and determine the level of cognitive ability. The classical methods are time-consuming and require the presence of personalized and full-time supervision by experts. In addition, classical methods have the form of a test, which can affect alertness, effort, motivation and, of course, the end result. Technology advancements and the attempt to combine scientific fields to find solutions to such problems led to the introduction of computer technology to address them.

The evolution of technology now provides the possibility of cognitive interventions through computer programs, electronic games and mobile applications. These innovations seem to be gaining ground in the field of rehabilitation compared to traditional methods, as they are less costly, more flexible, and more and more people have access to these techniques [8].

In an attempt to use these results, serious games have been developed with the aim of strengthening the brain and cognitive abilities. Serious games include focused activities derived from specific scientific measures of cognitive functions. This new kind of games has been extremely popular around the world, especially in elderly adults as these games have beneficial effects [9].

2 Related Work

Previous studies showed that playing serious games could improve cognitive functions such as memory, orientation, attention and more. Valladares-Rodriguez et al. introduced Episodix [10], a serious game application, designed to detect MCI and AD. It was used to assess cognitive domains such as memory, attention and knowledge, with a set of six games based mainly on classical psychological tests. The application was tested by a group of 16 individuals comprising eight healthy users, three with MCI and five with AD.

Boletsis and McCallum developed Smartkuber, a serious game that uses Augmented Reality [11]. The main purpose of the game was cognitive screening aiming mainly at people with MCI. The game consists of many minigames for a variety of puzzles and aimed at different areas of cognitive behavior, including audiovisual logic, memory, attention, problem solving and logic. The application was evaluated with a sample of 13 individuals over 60 years old. The results showed a good overall correlation (0.81) between Smartkuber and Montreal Cognitive Assessment (MoCA) test.

Leduc-McNiven et al. presented a serious game called WarCAT [12]. The aim of the game was to detect changes in cognitive behavior in an elderly patient with MCI. They have also successfully used a machine learning model to detect deviations in cognitive behavior.

Chignell and Tong developed a serious game for cognitive status assessment in the elderly [13]. Evaluating the application resulted in statistically significant correlations between game performance and the results of MoCA cognitive test measurement. They also found that the serious game could be used as a first check diagnosis of delirium.

Tapbrain is a mobile and tablet application that combines 13 serious games, in order to stimulate brain activity and 4 serious games to induce physical activity [14]. The goal is to influence cognitive areas such as memory, attention, problem solving, decision making, and games to develop physical activity, developing five successive stages of patient activation.

Finally, Manera et al. examined the acceptance degree of the Kitchen and Cooking serious game by elderly patients with MCI [15]. The study sample consisted of 21 elderly people with and without cognitive impairment. At the end, by evaluating the results, it was found that patients with AD were slower regarding the completion time of scenarios and recorded lower scores in the memory scenarios than the MCI patients. Participants with AD had a higher apathy score than participants with MCI.

3 MCI Rehab Application

Our work presents and evaluates an application with ten serious games for improving cognitive health for elderly people with MCI. The MCI Rehab application can provide an informal measurement of the user's cognitive performance and an assessment of cognitive improvement by monitoring the total success game time.

3.1 Games Development

The MCI Rehab application includes ten serious games (Table 1). Each game targets one or more cognitive areas. The cognitive areas that were examined are: Attention, Visual Memory, Observation, Acoustic Memory, Language, Calculations, Observation, Orientation and Sensory Awareness.

All games can be played on a tablet using typical touchscreen interaction movements. For example, the user can select a desired object and drag it to the correct position. The application was developed using Android Studio as the main development environment.

In order to facilitate the users the design of the game screens have common characteristics (Fig. 1). For example, the button "EXIT" is always on the top right of the screen and allows users to return to the main menu whenever they like. The time the user has to complete the game, is always at the top left of the tablet screen in an effort to make it easier for the users, to become familiar with the functionality of the application. An introduction screen was created in each game containing instructions in order to help the users to understand faster the logic of the game. Because our users are elderly people with cognitive issues and in order to facilitate their engagement to the application, softer

Table 1. Description of the 10 games in MCI rehab application

Game name	Task	Cognitive function
Puzzle	The user must put the correct pieces of a photo to the correct place	Attention
Chronological order	The user is asked to create a story in chronological order by ordering a number of image pieces	Spatial and temporal orientation
Recall	The user must memorize a series of digits displayed in the screen and then must select it from a group of numbers	Visual memory
Mathematics	The user is asked to solve arithmetic problems	Calculations
Observation	The user is asked to group the images appearing on the screen	Observation
Sounds	The user is asked to match the sound heard with the correct image	Acoustic memory
Maze	The user is asked to lead a mouse on the cheese through a maze	Visual motor and attention
Memory cards	The user is asked to flip the cards and match the tiles together in pairs	Short memory
Language	The user is asked to find antonyms and synonyms of words	Language
Logical sequence	The user is asked to find the correct choice that continues a given sequence	Perception

colors and a larger font were used. Also, in each successful attempt the transition to the next level is done automatically to lower the interaction burden.

The application has been simplified as much as possible, as it was targeting people with cognitive impairments. As a design choice game screens should be as easy to use and enjoyable as possible. In this way, complexity should be avoided and easiness and clarity should be promoted, helping the user to be more focused on the game goal. Furthermore, the application allows the user to choose to play the games at different levels of difficulty depending on his/her capabilities. The choice of difficulty level is individual per user, affects all games, and is continuous in terms of time, as it is valid continuously until it changes from another option.

Three different basic difficulty levels have been defined: easy, medium and advanced. Each level adds a relative playing difficulty compared to the previous one. When the user successfully completes each level then a custom dialog box appears, encouraging the user to continue to the next level. At each level, the user has the possibility of three

Fig. 1. Screen shots of the MCI Rehab game application (main menu, chronological order, logical sequence, sounds, mathematics and maze)

attempts; on the third unsuccessful attempt the game is completed and recorded as a failure, returning the user to the main menu.

In any successfully completed level, the transition to the next level is automatic. In this way we want to avoid complexity and promote usability, helping the user to be more focused on the gameplay.

3.2 Data Collection

Collection of user performance data is an important feature of the application allowing the analysis of users' cognitive state. For this reason the application records all user actions for each game separately. The parameters collected by the game are summarized in Table 2. Each game must be completed at a maximum allowable time. If this time elapses then the game is completed and identified as a failure otherwise the user has successfully completed the game. We are interested in completion times and points gained by the users as these metrics show their performance and adherence to using the application. A positive trend is that future game session results (e.g. after two/three/four weeks) should be better than past ones.

Consequently, conclusions could be drawn on which games the performance was improved and therefore which cognitive field has trained best. On the other hand, cognitive stagnation can be identified through long game times and unsuccessful attempts by analyzing performance data collected per game and per level.

Table 2. Data collection in each game

Primary data	Player Anonymous Id
	Session Id
	Login date/Logout date
Parameters	Total time per game
	Total time per level
	Win games
	Lost games
	Number of touches per game
	Number of correct activities per game
	Number of wrong activities per game

4 Evaluation

In total, the user group in the pilot study consisted of 6 participants (equal number of male and female), aged 66–79 years (Avg = 72.0 years, Stdev = 5.10) and was assembled as an opportunistic sample. According to Nielsen and Landauer [16], five users is a sufficient number to reveal 85% of the usability problems. The education level varied between secondary (66.6%) and higher (33.3%). Exclusion criteria for all potential participants were defined as i) age lower than 65 years; ii) the presence of irreversible hearing problems; iii) loss of vision; and iv) any other serious physical, mental and neurological illness (e.g., cardiovascular disease, stroke, etc.). An additional exclusion criterion was the presence of cognitive impairment. A score lower than 26 on the Montreal Cognitive Assessment (MoCA) test [17] is considered indicative of notable cognitive impairment. Finally, the Mini Mental State Examination (MMSE) test [18] was administered as additional tool for describing the cognitive level of the participants and not as an exclusion tool.

At the beginning of the process the participants signed a written consent form to participate in the research. The pilot phase regarding the usage and testing of the MCI Rehab application lasted 33 days (March-April 2019). Each participant completed 10 sessions of 30 min during the pilot study as a simulation of a cognitive rehabilitation process.

By employing standard experimental evaluation methods in terms of a semi structured interview and a usability questionnaire both qualitative and quantitative data were collected. As a suitable tool for assessing the perceived usability of the game tool the System Usability Scale (SUS) was selected [19]. The administration of the questionnaire was performed digitally through the application. Each participant (with the help of the researcher) scored on a 5 Likert scale ten statements regarding their experience using the application. A total of three evaluations were performed by each participant during the study. Fig. 2 shows the results of a total of 18 evaluations. An average SUS score for all participants was estimated as 89.4 in the scale of 100, suggesting a higher user acceptance [20].

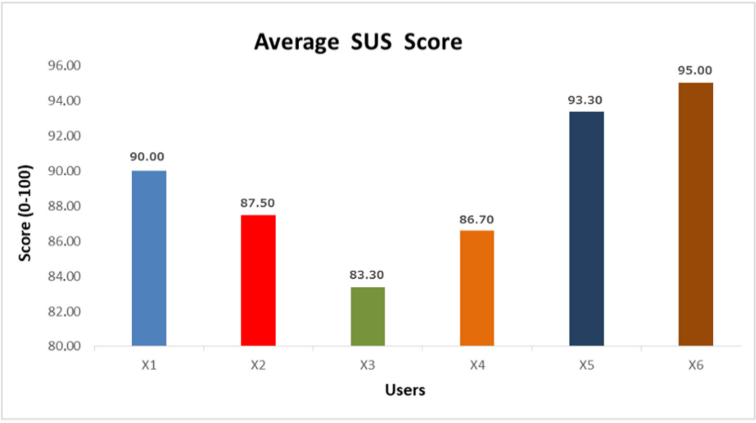

Fig. 2. Average SUS score per user

By analyzing the performance data collected by the application other interesting observations could be made. For example, for the user with id X1 even though a good overall cognitive assessment was originally recorded as attested by the MMSE and MoCA scores, by analyzing the results of specific cognitive domain tests separately, a lower performance was also noticed, especially in the domain of arithmetic calculations. While using the application the same user demonstrated similar poor cognitive performance in terms of successfully completing games that were related to arithmetic operations. As shown in Fig. 3 the user's playing time was quite high and had continuous failures to complete sessions of the Mathematics game. This result, demonstrates the potential effectiveness of games in detecting specific cognitive deficiencies. In more general, this is a promising indication that the use of such game applications can be utilized by experts as a tool to test specific cognitive abilities, as an alternative to traditional methods.

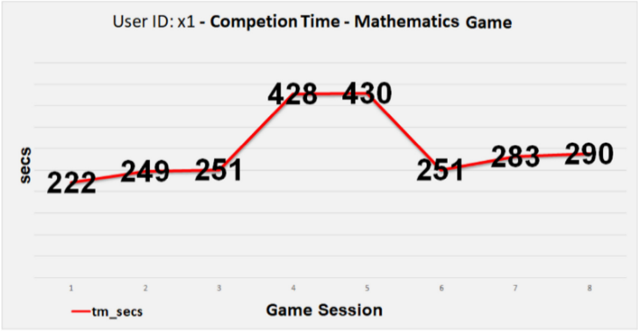

Fig. 3. Mathematics game completion times for participant with id X1

Figure 4 shows the average completion time improvement for all the participants in the beginning and in the end of the pilot study. During the first session an average

completion time of 82 s and a standard deviation of 23.20 s were observed. In the last session a decrease of the average completion time to 42.50 s with a standard deviation of 4.26 s was observed. This indicates a significant improvement in the game completion times of the participants, and also a stability in the level of their performance as outliers have been eliminated.

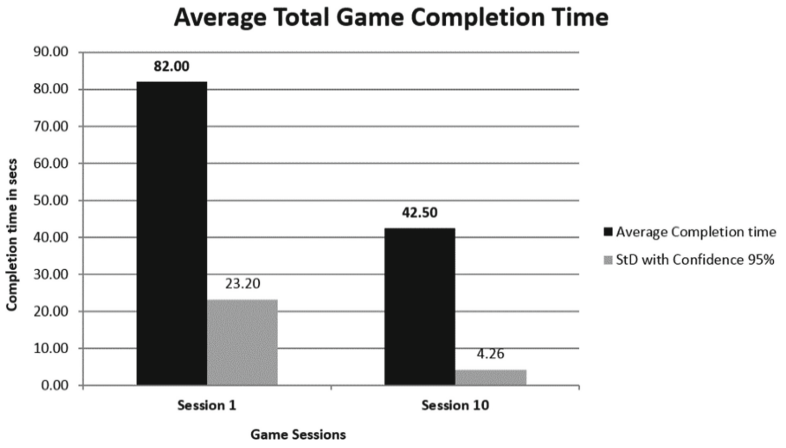

Fig. 4. Performance improvement in terms of successful game completion time due to practice between the first and last sessions

Overall, these measurements may be indicative that the game screens and tasks were well designed for the elderly people and that they were also sufficiently demanding to engage them to put additional effort for achieving improved performance throughout continuous training.

Finally, all participants attended at the end of the study an interview session to acquire qualitative data. There are no right or wrong answers. The feedback acquired reflects the subjective perception of each participant regarding the usefulness of the game tool. By analyzing their responses, the majority of the participants agree that the games are enjoyable and by supporting different levels of difficulty makes them challenging to continue the effort. The presence of other gamification techniques, such as points, statistics and leaderboards was also seen as a motivating factor. Other feedback given was that game tool learning can be done quickly and that a low mental load is required for playing while they estimated that they had a good performance (confirmed by the measured performance of the application). A notable feedback given by the more elder participants was their belief that their cognitive operation and especially memory will probably improve by practicing more with the games. Actually, the majority of participants expressed their interest to continue using the games after the pilot even just for the fun.

5 Conclusions

Given the growing need to implement more effective cognitive interventions in MCI patients or healthy groups of the population, research should focus on new technological developments, such as mobile applications, which combine cognitive training with fun, enjoyment, adaptation and easy access. This study confirms previous studies that properly designed serious games can be used as cognitive training programs for the elderly. A limitation of the present study is that the sample is small to draw safe conclusions. A larger, non-opportunistic sample would provide more consistent measurements regarding the feasibility of the approach.

Regarding the MCI rehabilitation dimension of the game tool, an extensive evaluation is underway in the context of a research project. The methodology includes a control group and an intervention group applying a randomized controlled trial. For all users, measurements of cognitive functions will be recorded before using the game tool, while after the intervention, the same measurements will be recorded only for the intervention team. The intervention team will use the game tool 1–2 times a week until each participant completes 24 user sessions.

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