dHealth 2022
G. Schreier et al. (Eds.)

doi:10.3233/SHTI220366

Alzheimer's Disease and Mild Cognitive Impairment Serious Games: A Systematic Analysis in Smartphone Application Markets

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Abstract. Background: Patients with Alzheimer's disease and mild cognitive impairment can employ serious games to assess and improve their cognitive status. Objectives: To determine the cognitive aspects of the MMSE and ACE-R tests that are supported by available games. Methods: We searched cognitive games available in online application markets (Play Store, Galaxy Store, and App Store) using keywords: Alzheimer's Disease, dementia, and mild cognitive impairment. Game scenarios were extracted and assessed by a neurologist to determine the appropriateness of the scenarios for patients and cognitive aspects supported by the games. Results: We found 416 games; 135 of them were duplicates, and 237 of them were completely irrelevant to the study objective. A neurologist evaluated the remaining scenarios to see if aspects of each scenario matched the MMSE and ACE-R tests. There were 37 scenarios left in the end. These scenarios are associated with 18 different games. Most of the available scenarios are suitable for attention and orientation. Conclusion: Existing cognitive games may be used to several different cognitive aspects. Some of these scenarios have been used to assess cognitive status, while others have been used to improve it. The majority of available cognitive games have not been subjected to any research. As a result, it is unclear what impact they could have on the cognitive condition of the elderly with cognitive impairment. As a result, it is critical to assess these games.

Keywords. Serious game, Alzheimer disease, Early diagnosis, Mild cognitive impairment

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1. Introduction

Life expectancy has risen as a result of health care improvement. Alzheimer's disease (AD) is one of the age-related disorders, with the incidence of AD increasing with the number of senior persons in the society [1]. Alzheimer's disease manifests itself in a variety of ways. Some will appear in the early stages of the disease, while others will appear as the condition advances. Mild cognitive impairment (MCI) is one of the initial indications of Alzheimer's disease [2]. Early detection of these cognitive impairments helps the aged to take advantage of appropriate and early disease diagnosis, such as the ability to choose approaches to reduce disease progression. As long as persons with cognitive impairment are still able to make key decisions regarding their future care, early recognition allows them to develop a comprehensive plan [3]. AD/MCI are diagnosed using the mini-mental state examination (MMSE) and Addenbrooke's examination – Revised (ACE-R) tests[4]. In a range of clinics, research, and community contexts, the MMSE and ACE-R tests are employed as the most well-known short-term screening instruments for the general evaluation of cognitive impairments. These tests evaluate a variety of cognitive aspects including Attention and orientation, Memory, Fluency, Language, Visuospatial. However, there are limitations in these tests that emphasize the need for new technologies to assist overcome them [3, 4].

Serious health-related games can be an innovative tool for diagnosing and supporting persons with behavioral and mental disorders to improve their health care [5]. Virtual settings with integrated elements for psychological examinations, which are problematic in traditional tests, are one of the strengths of using serious games in cognitive assessments [6]. There are several varieties of cognitive games available for smartphones nowadays. The impact of these games on cognitive status is important, given that the target audience for these games is the elderly who suffer from cognitive disorders. At present, it is unclear how suitable these games are for the elderly with cognitive impairment, and further research is required.

The objective of this study was to find available games and their scenarios in the field of AD/MCI, as well as the potential of using these scenarios to assess the cognitive status of senior people at risk of AD/MCI. In addition, these scenarios were evaluated for compliance with the cognitive aspects of the MMSE and ACE-R tests.

2. Methods

A review of cognitive games available in smartphone application markets was conducted in this study. All games on the Play Store, Galaxy Store, and App Store were searched using these keywords: "Alzheimer's disease", dementia, and "mild cognitive impairment". On February 8, 2020, a search was done. If the games had a clear game logic and scenarios and could be employed in the context of AD/MCI, they were chosen, and game scenarios were extracted from these games.

Inclusion criteria for each game were as follows: games were freely available, available for the elderly, developed to examine the cognitive aspects assessed to diagnose cognitive impairment and Alzheimer's disease, having over 1000 downloads and rated at least 4 stars by users. The investigation was carried out by two independent persons. They reviewed each game in terms of the inclusion criteria, and in the event of a disagreement, the case was resolved through a meeting and discussion. Inappropriate games for AD/MCI patients were excluded. Appropriateness was determined by a

neurologist. In addition, a neurologist analyzed the scenarios of included games to evaluate and map scenarios of each game to the cognitive aspects assessed in the MMSE and ACE-R tests.

In addition, we searched the literature to find any research studies related to the selected games (scenarios) to find any evidence related to utilizing these scenarios by elderly people with AD/MCI. To this end, we searched PubMed and google scholar using the related keywords (name of the game or the relevant scenarios) to find any experimental studies regarding the included games/scenarios.

3. Results

There were 316 games found in the Play Store market, while 100 games were identified in the App Store market. There were no results for the Galaxy Store Market. In all, 135 of the 416 games were duplicates, while 237 were completely irrelevant to the research objective and AD/MCI. In the end, 44 games were left, and 150 scenarios were taken from these games.

The scenarios were then evaluated by a neurologist to see whether cognitive aspects of each MMSE and ACE-R test were appropriate for each scenario. 74 of these scenarios were not found to be appropriate for AD/MCI patients, and 39 of them missed any cognitive aspects of the MMSE and ACE-R tests. 37 scenarios remained in the end. The scenarios in this collection are from 16 distinct games. These games were as follow: Neurobics: 60 Brain Games, Big Brain – Functional Brain Training, Brain Games, Brain Memory Exercise, KettleMind – Competitive Brain Games, Stimulus LITE Brain Challenges, Train your Brain – Attention Games, Train your Brain – Memory Games, Train your Brain 2, Brain School: Brain Games, Brainilis – Brain Games, Super Brain Training, BrainExer 2, Elevate your Brain Training, Logical Reasoning, and Mind Games.

Table 1. Extracted scenarios

ID	Scenario
1	Some numbers or alphabets are shown in circles dispersed throughout the screen without any order and the user must click on the circles in small to large or alphabetical order (After a while, the numbers or characters disappear) [7-10].
2	The whole cell is whitewashed after numerous cells of the matrix have been painted. The player must figure out which cells were painted initially [9-17].
3	A rabbit walks the path on the grid and then returns to the cell where the stage began. After that, the rabbit's route vanishes. The player must draw the path in the matrix, with his finger on the cells [10].
4	Pictures are shown in a matrix of cells. After that, the pictures vanish from the screen. A question mark appears in one of the cells where the picture was previously located, and some pictures are shown at the bottom of the screen. The player must tap the image that was previously in the cell with a question mark [10, 11, 15].
5	Players should remember each picture location, and then place each image in its correct spot on a new page [11].
6	The animals descend sequentially from the top of the screen (in line). The player should drag each animal to the side that was originally designated for it [13].

ID	Scenario
7	The player is given a series of words. The player determines whether the word has a positive or negative connotation by using the + or - keys [7].
8	A colorful picture, as well as a sequence of greyscale pictures, are shown. The player must decide which greyscale picture represents the shadow of the colorful object [10].
9	A stack of squares is ranging in size from large to small. Based on the color arrangement of the squares, the player must recognize the picture of their side view, which resembles a pyramid [9, 10, 18].
10	The player must identify the image created by combining numerous geometric shapes [18].
11	On the screen, there are several rotating foods. The player should tap food that spins faster [10].
12	Three horses are running in a three-row arrangement. The player must hit the horse that is running the quickest [19].
13	It begins with an image and continues to add one image at a time. The player must indicate which image is new and has been added recently [7, 9, 10, 14, 15, 17, 18, 20].
14	If the current picture has not yet been displayed on the screen, the player must move his hand to the right of the screen each time an image shows on the screen. He must drag his hand to the left of the screen if it is a repetition [10].
15	The user must recall the image of the items he or she wants to buy. After that, he must select them from the shop shelves (There are no names for the items, so the player must remember their form and color.) [20].
16	A great number of things are displayed next to each other. Some item names are displayed at the top of the page, and the user must locate these things among the objects at the bottom [13].
17	First, there are the ingredients. The chef wishes to prepare a pizza using the specified quantity of ingredients, which the player must recall. The chef must next choose elements from the collection of goods offered to the player in the number specified in the previous phase and arrange them on the pizza in the following stage [14].
18	Several pictures are displayed and then one of them disappears. From the given options, the player must select the deleted picture [18].
19	Certain numbers are added or subtracted. The player must select the results of the equation from the options [7, 9, 10, 12, 15, 17-21].
20	The result of a mathematical expression is displayed without any operators. For this expression, the player must choose a suitable operator [10, 11, 15, 17].
21	There are two numbers on the screen. Each time, the player must choose a higher number [9, 10, 12].
22	Two computational expressions are compared (which value is greater) [18].
23	Follow the clock to make sure you do not miss any digits [9].
24	The cards have the names of numerous months of the year inscribed on them. After then, the backs of the cards are displayed. The player must touch the cards in the correct order of months [18].
25	The game shows a variety of animals of various sizes. After that, the backs of the cards are displayed. The cards must be clicked from lightest to heaviest or inversely [18].
26	In the sequence of numbers, a number is eliminated. It is up to the player to discover it [11].

ID	Scenario
27	A number is represented inside a geometric form. Both must be remembered by the player. In the following phase, the player is asked to identify the number or geometric shape [10, 17, 18, 20].
28	Some birds are displayed on the screen. The birds then open and close their wings, respectively. The player must then tap the birds in the same sequence that the birds opened and closed their wings [10].
29	Players should make words using the letters provided [9].
30	Players should guess the word with the scrambled letters [9, 17].
31	Players should check the spelling of the provided words [9, 17].
32	The player should analyze the given sentence grammar [9].
33	A word is given. The player must select the most appropriate meaning (synonym) from the available possibilities [17].
34	There are two words on the screen. The player must quickly tap the synonym or antonym button and explain how the two terms are related [9, 17].
35	A word is given. There are four possibilities, one of which is made up of the letters of the same word as the previous one. The player must select the appropriate choice [22].
36	Players should describe how each device or organ is used in the rationale area [9].
37	A flying insect and a sweet are shown. The fly must be hit just before it lands on the sweet. Because the fly is flying, it must hit the fly with the correct precision and speed to get the required points [20].

Table 2 lists the cognitive aspects that the neurologist assigned to each scenario. In this Table, "The number of scenarios in Table 1" column is referred to the "ID" column in Table 1. As seen, most scenarios are suitable for attention and orientation, and memory.

Table 2 .Scenario row number for each cognitive aspect

MMSE and ACE-R Cognitive aspects	The number of scenarios in Table 1	Frequency
Attention and orientation	1,2,3,8,11,12,13,14,15,19,20,21,22,24,25,26,27	17
Memory	1,2,3,5,14,15,17,18,24,25,27,28	12
Fluency	16,34,35	3
Language	4,6,7,29,30,31,32,33,34,35,36	11
Visuospatial	5,9,10,11,12,23,37	7

4. Discussion

We found that cognitive game scenarios can be applied to a variety of cognitive aspects, and available games cover all of the cognitive aspects of the MMSE and ACE-R tests. As shown in Table 2, most of the available scenarios are suitable for attention and orientation. There are also many scenarios for memory and language in the App markets. However, fewer scenarios are appropriate for fluency and visuospatial.

We found that there were no research results about outcomes of these game in none of the markets, consequently users do not have access such evidence through the App markets. Through our literature review, we found that 16 scenarios (in Table 1: 1,2,3,5,6,7,9,19,21,25,28,29,32,33,34,35) were evaluated in studies on the use of serious games in AD/MCI. The results of playing these games have been observed in two areas: cognitive assessment [23-33] and cognitive improvement [31, 32, 34-37].

The degree of correlation between test results such as the MMSE and the ACE-R and games results have been investigated in some studies. Researchers employed these scenarios (2,3,5,6,7,9,19,28,29,33,34,35 in Table 1) for cognitive evaluation. A positive correlation was reported for these scenarios: 2,5,6,7,19,29,33, 34, 35 [23-28, 30, 31, 33, 34, 36]. For the scenario 2, for example, researchers found a 0.82 correlation between the results of the game played by the individuals with cognitive impairment and the results of the MMSE and ACE-RT tests [26]. As a result, with such a high correlation, it may be assumed that these games can be utilized for early diagnosis.

Machine learning and classification algorithms have also been used on data obtained from playing these games to show the effectiveness of these games (scenarios) for diagnosing the cognitive status of the elderly [27, 35, 38]. These indications are reported for scenarios 2, 5,6,9, and 28. Scenario 2, for example, reports accuracy, sensitivity, and specificity of 82.5%, 93.1%, and 64.3%, respectively [27]. On the data from playing scenario 2, logistic regression (LR), classification and regression test (CART), and support vector machine (SVM) algorithms achieved F-measure values of 0.55, 0.62, and 0.85, respectively, to diagnose the disease [38]. Similarly, using the LR, CART, and SVM algorithms on data from scenario 5, F-measure values of 0.74, 0.96, and 0.96 were achieved, respectively [38].

In studies related to improving the cognitive status of the elderly, these scenarios (1,2,5,6,9,21,25,28,29,32 in Table 1) were applied and the cognitive status of individuals has been reported before and after playing the game. In scenario 9, for example, the average number of accurate responses at the start of the game was 29%, and after playing for a length of time, the average was 36% [35]. For scenario 28, the accuracy of right responses was 84% at the start of the research and 95% after playing for some time [35]. It shows that playing this scenario can be utilized for cognitive improvement. Scenario 3 was also utilized for cognitive improvement. The average MMSE score of participants at the start of the study was 21.8, and after three months of playing this scenario, the average MMSE score of participants improved to 27.4 [31].

In both cognitive assessment and cognitive improvement, a variety of scenarios have been employed (Scenarios number 2,5,6,9,28). However, we could not find any studies for 21 of the evaluated scenarios, and the effect of playing these scenarios is currently unclear, indicating that additional research is needed in this area. Furthermore, there are other scenarios for these patients that have not been considered appropriate by a neurologist; however, they are freely available on the smartphone application markets and have been downloaded numerous times. Their appropriateness is debatable and must be assessed in future studies.

Some limitations should be considered. We only searched App markets. Obviously, there may be other games used in healthcare or research settings that we did not investigate them. Therefore, other studies are strongly suggested to analyze those games reported in the literature.

5. Conclusion

Available cognitive games may be used to a series of diverse cognitive aspects. Some of these scenarios have been successfully used to assess cognitive status, while others have been used to improve it. In AD/MCI, several scenarios can be utilized to both assess and improve cognitive status. The majority of existing cognitive games have not been investigated in scientific studies; therefore, it is unclear what effect they could have on the cognitive status of elderly people with cognitive impairment. As a result, it is critical to assess these games.

Acknowledgment

This work is a part of a Ph.D. dissertation supported by the Iran University of Medical Sciences (IUMS/SHMIS_97-4-37-14193). This study received approval from Research Ethics Committee of the Iran University of Medical Sciences (IR.IUMS.REC.1397.1364).

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