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USE OF SERIOUS GAMES FOR THE ASSESSMENT OF MILD COGNITIVE IMPAIRMENT IN THE ELDERLY

Abstract

This study investigated the use of computer games to detect the symptoms of mild cognitive impairment (MCI), an early stage of dementia, in the elderly. To this end, three serious games were used to measure the visio-perception coordination and psychomotor abilities, spatial memory, and short-term digit span memory. Subsequently, the correlations between the results of the games and the results of the Korean Mini-Mental State Examination (K-MMSE), a dementia screening test, were analyzed. In addition, the game results of normal elderly persons were compared with those of elderly patients who exhibited MCI symptoms. The results indicated that the game play time and the frequency of errors had significant correlations with K-MMSE. Significant differences were also found in several factors between the control group and the group with MCI. Based on these findings, the advantages and disadvantages of using serious games as tools for screening mild cognitive impairment were discussed.

1. INTRODUCTION

Serious games refer to games designed with content devised to achieve specific objectives in areas such as education, training, and health through fun and accessible everyday play. The utilization value of serious games is significant as they provide education, training, or testing through motivational content, and their accessibility enables processes that previously needed to be experienced face-to-face or directly to be carried out on a large scale through computers and online access (Granic, Lobel, & Engels, 2014).

Serious games are particularly useful in large-scale medical diagnosis and in screening for jobs. One of the recent leading applications has been medical serious games used for testing cognitive impairment or dementia in the elderly. Given the difficulty of completely curing dementia once it has developed, discovering and responding to initial symptoms at an early stage provides a decisive advantage for managing the disease and preventing it from becoming severe. The difficulty of discerning early dementia or mild cognitive impairment (MCI) requires the repeated testing of a large number of the elderly. Such ongoing large-scale testing is problematic (Connolly, Gaehl, Martin, Morris, & Purandare, 2011; Lopponen, Raiha, Isoaho, Vahlberg, & Kivela, 2003; Scanlon, O'Shea, O'Caomh, Timmons, 2015).

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Consequently, it is highly useful to develop digital content such as serious games that are easily accessible, can accommodate many users simultaneously, prevent boredom during tests, and can be carried out in a fun way.

This study aimed to determine the possibility of diagnosing MCI, an early stage of dementia, by applying various cognitive measurement algorithms related to MCI to computer-based serious games. To this end, this study implemented three cognitive measurement algorithms based on MCI in the form of serious games and compared various behavior data from playing the games between a control group and patient group who actually showed MCI symptoms. In addition, the results of the games were analyzed by comparing them with the results of the Korean Mini-Mental State Examination (K-MMSE), a specialized dementia screening test.

1.1. Serious games for dementia prevention

The development of digital cognitive measurement tools and serious games has substantially progressed over the last two decades, and extensive research is still ongoing (Beavis, Dezuanni & O'Mara, 2017). In particular, much functional content for the elderly has been developed to prevent and treat mental or physical degeneration and associated changes. Current serious games for elderly healthcare aim to enhance their physical and mental well-being, and many programs such as Nintendo, Lumosity, Smacare, Brain Training, Elevate Labs, and Psicoool have been developed and commercialized.

An especially notable trend is that, although serious games were originally simple training programs created based on experts' recommendations or commonsense, recently they are being applied to specific diagnoses and treatments through more scientific and clinical experiments. For example, Manera et al. (2015) conducted experiments to measure the amnesic mild cognitive impairment (aMCI) and dementia of 21 patients using a serious game called "Kitchen and Cooking" and obtained significant results. Tong, Chignell, Tierney and Lee (2016) also examined whether it is possible for game-based tests to measure cognitive impairment. In addition, various scientific attempts are being made for mental health promotion and testing through digital applications using computerized touch-panels (Fukui et al., 2015), augmented reality, or virtual reality based cognitive training applications (Allain et al., 2014; Boletsis & McCallum, 2016; Tong, Chignell & Tierney, 2016; Zygouris et al., 2015).

Although considerable researches demonstrated that serious games were highly correlated with other methods of cognitive assessment for MCI and dementia, this field is quiet young and more questions and researches are needed. In this study, we tried to verify the possibility of diagnosing MCI with computer game trying to improve two aspects of previous studies. First, most of previous researches compared the simple game score between healthy group and MCI group. However, in computer-based serious games, various behavioral data, as well as the targeted cognitive aspects, can be systematically and efficiently collected and assessed and various characteristics associated to target disorder can be analyzed with the data. Second, most of previous researches used small size of sample less than 25 participants. However, for using serious game as diagnostic tools for massive population to screen clinical and pre-clinical conditions in the early stages of MCI, we need to verify the validity of serious games in a similar condition.

1.2. Assessment of cognitive impairment

Alzheimer's disease, a degenerative disease, is characterized by gradual onset and progression, and cognitive impairment gradually develops before full-scale behavioral and neurological symptoms are evident (World Health Organization, 2019). MCI refers to this stage of preclinical Alzheimer's disease. This is a condition in which, clinically, cognitive abilities and functional activities are relatively preserved, except for memory that has deteriorated with age. Furthermore, daily unassisted living is still possible and a diagnosis of dementia is unwarranted (Langa, & Levine, 2014). The diagnosis of MCI is important in several aspects. Early diagnosis enables the healthy period of the patient to be prolonged through early management and treatment, it allows patients to plan for the future and enables patients to preserve their quality of life (Ismail, Rajji & Shulman, 2010).

There are two main types of diagnostic tools for MCI or early dementia: screening tests and neuropsychological tests. Screening tests roughly evaluate the state of cognitive functions and the existence or absence of cognitive decline, whereas neuropsychological tests evaluate each sub-cognitive domain in detail. A representative example of the former is the MMSE (Folstein, Folstein & McHugh, 1975), which is the test most widely used. A representative example of the latter is the Consortium to Establish a Registry for Alzheimer's Disease (CERAD) assessment packet (Morris et al., 1989).

Although these two tests are considered the standard methods, with proven reliability and validity for the diagnosis of MCI (Baek, Kim, Park, & Kim, 2016), they have several limitations. Because they are pencil-and-paper-based methods, they must be carried out face-to-face and are thus not suitable diagnostic tools when we wish to assess the cognitive problems of a large number of people simultaneously. In contrast, serious games can be a good solution. With computer-based serious games, cognitive impairment and, further, the changes or reduction in cognitive abilities can be systematically measured, analyzed, and managed by repetitive play on a computer or a smartphone. This allows for the identification of dementia risk groups, which can, in turn, lead to more professional examination and treatment in partnership with specialized treatment institutions such as geriatric hospitals.

2. METHOD

2.1. Participants

The Ansan Geriatric Study in Korea – an ongoing prospective population-based cohort study among subjects that are at least 60 years old and live in the Korean city of Ansan – provided the clinical information and participants for this study. The participants in this study were 342 of 588 elderly people who participated in the Ansan Geriatric Study and who consented to participate in this study. Informed written consent for participation was obtained from each individual. Of the 342 participants, 62 were diagnosed as having an amnesic type of MCI and 280 as having no cognitive impairment (control).

2.2. Materials

2.2.1. Computerized assessment tools (serious games)

This study used three serious games: “Get Persimmon,” “Set the Table,” and “Elevator.” These computer games are prototypes developed for cognitive measurement by specialized programmers and have relatively simple goals and levels (difficulty).



Fig. 1. Screenshots of the games “Get Persimmon,” “Set the Table,” and “Elevator”

The first game, Get Persimmon, assesses visio-perception coordination and psychomotor ability (see Figure 1). In this game, there is a bear doll on the screen that can be moved with the mouse to receive falling persimmons. There are two types of persimmons: dark purple rotten persimmons and scarlet ripe persimmons. Participants must avoid rotten persimmons and catch ripe persimmons before they fall to the ground. The number of falling persimmons changes over time. In this study, one level was set for measurement. The measured variables were total play time and mouse moving distance until the preset number of persimmons (50) was received.

The second game, Set the Table, assesses spatial memory and visual short-term memory (see Figure 1). Specifically, it assesses the ability to remember the types and positions of side dishes on the table and reproduce them correctly on the table. There are two difficulty levels: Levels 1 and 2. Participants first look at a picture that is shown to them and are then required to find and place, in their original positions, three foods in Level 1 and six foods in Level 2. Each level is played three times, and if the participant makes five or more errors, the game moves on to the next trial. The assessment variables are the total performance time at each level, number of errors until the game is finished, and reaction time from watching the presented picture until starting to set the table.

The third game, Elevator, is the same as the digit span task that assesses auditory short-term memory (see Figure 1). The participants must listen to the number of floors that the elevator must stop at and push the relevant floor numbers. There are two levels of difficulty: Levels 1 and 2. Participants must press the buttons in the correct order after listening to three floors in Level 1 and six floors in Level 2. Each level is played three times, and if the participant makes five or more errors, the game moves on to the next trial. The assessment variables are the time it takes until the correct buttons are pressed at each level and number of errors.

2.2.2. Korean Mini-Mental State Examination (K-MMSE)

This study used the K-MMSE, created by Kwon and Park (1989) for the Korean elderly and which revised the MMSE that was developed as a screening test for cognitive impairment and dementia in the elderly by Folstein et al. (1975). It is a widely used tool with proven reliability and validity (Cronbach's α of 0.86). K-MMSE consists of 19 questions that measure time orientation (5 points), spatial orientation (5 points), memory registration (3 points), attention and calculation (5 points), memory recall (3 points), language (8 points), and space–time configuration (1 point). The highest score is 30 points with a higher score signifying higher cognitive function. Scores in the range of 18 to 23 are associated with MCI, and scores below this range signify severe cognitive impairment.

2.3. Process

We analyzed the results of games played by participants after they had undergone a medical examination at the hospital. They played the games on three laptop computers. No penalty was given if they stopped a game in the middle or moved on to a different game. The experimenter collected simple personal information (to match with the clinical information provided by the Ansan Geriatric Study) from the participants who finished at least one of the three games and gave them simple souvenirs as a reward for participating.

3. RESULTS

Participant data were included in the results only if each level unit was played from the beginning to the end in each game; the data of the uncompleted level units were excluded from the analysis. First, the demographic and clinical characteristics were compared, via unpaired Student t test or ANOVA for continuous variables and by χ^2 test for categorical variables, and the analysis was performed using SPSS for Windows, version 18.0. The two groups had significant differences in age and education, but not gender. The average age of the MCI group was two years older than that of the control, and the education of the MCI group was also higher. Moreover, the K-MMSE score for screening dementia also showed a statistically significant difference (see Table 1).

Tab. 1. Mean and standard deviation (in parentheses) for MCI and control group in age, gender, education, and K-MMSE.

Characteristics of Participants	MCI (n = 62)	Control (n = 280)	p-value
Age	73.11 (5.63)	71.22±4.36	0.004*
Gender	62 (18.1%)	280 (81.9%)	1.00a
Education	6.50 (4.57)	8.34 (4.95)	0.006*
K-MMSE	25.13 (3.07)	27.44 (2.00)	0.000*b

* values are presented as mean (SD) or number (%), *P < 0.05: a) χ^2 test for Gender and Clinical group, b) ANCOVA test adjusted for Age and Education

Second, the correlations of the game results with age, education, and K-MMSE were analyzed. Age appears to influence the performance of the games in general. In the Get Persimmon game, age showed a correlation with time. In the Set the Table and Elevator games, age and time showed a positive correlation at the higher level of each game. In the Elevator game, which measures the digit span, age showed a correlation with the number of errors. This implies that age can be an important variable in cognitive aspects, although the correlations were not consistent across the games. Education was another important variable that can influence the result of games. Education showed negative correlations with both the playing time of the game and several other factors. The results of the games also showed a strong correlation with the K-MMSE results. The K-MMSE generally exhibited a negative correlation with the playing time, and the correlation became more general as the difficulty level increased (see Table 2).

Tab. 2. Correlations coefficient between game results and K-MMSE, Age, and Education

Game	Level	Game factors	Age	Education	K-MMSE
“Get Persimmon”		Playing time	0.146*	-0.206*	-0.306*
		Moving distance	-0.004	0.141*	0.099
“Set the Table”	Level 1	Number of errors	-0.011	0.006	-0.105
		Reaction time	-0.002	-0.149*	-0.181*
		Playing Time	0.062	-0.210*	-0.308*
	Level 2	Number of errors	0.044	-0.120	-0.139*
		Reaction time	0.114	-0.207*	-0.275*
		Playing Time	0.128*	-0.349*	-0.319*
“Elevator”	Level 1	Number of errors	0.160*	-0.007	-0.052
		Playing time	0.051	-0.138*	-0.137*
	Level 2	Number of errors	0.135*	-0.199*	-0.320*
		Playing time	0.123*	-0.356*	-0.504*

* P < 0.05

Next, the game results were compared between the control and MCI groups. Given the possibility that age and education might be covariates, they were controlled for. In fact, the differences between the two groups in the results of games by controlling the influence of age and education disappeared in the game playing time. The differences in game playing time were not statistically significant for the Get Persimmon game, which measures visual perception and motor skills, and for the Set the Table game, which measures short-term spatial memory. In contrast, statistical differences were observed in the Elevator game, which measures the digit span, but only in Level 2 of the game. Surprisingly, the difference in reaction time from seeing the items to memorize until actually taking action to play the game in the Set the Table game was significant in both Levels 1 and 2, even when the influence of age and education were controlled. This indicates that cognitive impairment is not simply associated with long playing time.

The last difference between the two groups is the number of errors. The number of errors showed statistically significant differences in Level 2 of the Set the Table game and Level 2 of the Elevator game and not in Level 1 in both games. This suggests that MCI is related to the number of errors only when the games require some level of difficulty.

Tab. 3. Mean and standard deviation (in parentheses) for MCI and control group in game results and *F*-value and *P*-value in ANCOVA test adjusted for Age and Education.

Game	Level	Game factors	MCI	Control	<i>F</i> -value	<i>P</i> -value
“Get Persimmon”		Playing time	83.06 (19.32)	76.25 (18.37)	3.6	0.059
		Moving distance	6078.51 (2668.82)	6398.94 (2939.76)	0.28	0.595
“Set the Table”	Level 1	Number of errors	0.42 (0.90)	0.39 (1.01)	0.05	0.821
		Reaction time	6.79 (5.08)	5.16 (2.89)	8.4	0.004*
		Playing time	59.04 (20.73)	56.47 (19.48)	0.04	0.833
	Level 2	Number of errors	3.27 (3.70)	2.20 (2.50)	4.04	0.045*
		Reaction time	10.29 (7.35)	7.77 (4.21)	6.36	0.012*
		Playing time	77.46 (36.03)	66.64 (27.76)	1.44	0.231
“Elevator”	Level 1	Number of errors	0.70 (1.25)	.56 (1.27)	0.14	0.705
		Playing time	12.94 (10.32)	10.99 (9.18)	1.23	0.268
	Level 2	Number of errors	0.98 (1.77)	2.34 (3.42)	16.27	0.000*
		Playing time	25.59 (15.18)	16.42 (9.67)	26.57	0.000*

* $P < 0.05$

4. DISCUSSIONS

Dementia currently has no treatment that can reverse the cognitive decline and restore cognitive functions to their prior levels. The only realistically possible countermeasure is to lower the incidence rate by controlling risk factors for dementia in advance and to retard the progression of dementia symptoms through early diagnosis and appropriate interventions (National Institute of Dementia, 2019). Therefore, intervention and cognitive assessment to diagnose MCI have crucial significance. The large-scale identification of early symptoms such as MCI cannot be achieved solely by the standard medical approach of pencil-and-paper testing; a more convergent approach that includes public healthcare and information and communication technologies is required.

This study aimed to determine the possibility of diagnosing MCI, an early stage of dementia, by applying various cognitive measurement algorithms related to MCI to computer-based serious games. To this end, the results of serious games were compared between patients with MCI symptoms and a control group, and also with the results of the K-MMSE specialized dementia screening test. The results show a clear difference in the K-MMSE between the MCI group and the control group, who were screened from the population over the age of 60 in Ansan, Korea. Moreover, the differences in age and education between the two groups also showed statistical significance, and similar tendencies can also be found in previous studies (e.g., Koster et al., 2005; Suh, Ju, Yeon, & Shah, 2004).

In the comparison between the game results and the K-MMSE, relatively strong correlations were observed in the game playing time, number of errors, and difficulty. However, we cannot exclude the possibility that the high correlations between the results of the serious games and K-MMSE could have been caused by the influence of age and education because it can be inferred that the age and education factors can have a significant effect on the cognitive performance related to the games. Consequently, an ANCOVA test was conducted to analyze whether the control group and the MCI group would show differences in the game results in a situation that excluded the influence of education and age. It was found that although there were differences by game and difficulty level, the results of the serious games showed their potential as auxiliary tests to distinguish between normal people and people with MCI, and also some limits. A few important implications and issues found based on analysis of the results are as follows.

First, the level of difficulty in games is very important in the design of games to distinguish between normal people and people with MCI. The games were designed with very low levels of difficulty in this study because the elderly are not accustomed to digital games. Hence, as shown in the results, the two groups exhibited no statistical difference; consequently, level 1 is not useful as a discriminator. By contrast, at Level 2, which is more difficult, the two groups showed a tendency of differences in game performance. Although more research is required regarding the relation between cognitive impairment severity and the difficulty of tasks, designing the level of difficulty to gradually increase from the very basic game level is deemed a crucial factor in serious games to distinguish between normal people and people with MCI.

Second, in computer-based serious games, various behavioral data, as well as the targeted cognitive aspects, can be systematically and efficiently collected and assessed. For example, the moving distance can be measured by mouse movement and the number of mouse clicks in the Get Persimmon game, and the types of errors, such as false positive or false negative error can be measured in the Elevator game. In this way, much behavioral data can be collected and analyzed for research on various aspects of disorder. For example, the reaction time from watching the presented picture until starting to set the table in the Set the Table game had not been expected at the beginning of the experiment to be conducive to distinguishing between normal people and people with MCI. However, this delayed reaction time can finally be employed as a highly useful factor for diagnosing MCI because such a difference in reaction time appeared regardless of the difficulty of the games. It appears to be associated with cognitive flexibility (Chelune & Baer, 1986) or executive function (Diamond, 2013), but more detailed research is required for a more accurate cognitive-based explanation. Nevertheless, this finding suggests that one of the advantages of using serious games as a diagnostic tool is that such diverse behavioral data can be derived and analyzed.

Third, cognitive abilities naturally decline with age rather than being preserved for the most part, and social factors like education may also make a difference. In other words, demographic factors such as age and education can have greater effects on game performance associated with cognitive functions. In particular, one of the major factors that can be influenced by demographic factors in serious games is playing time. As expected, the correlation analysis showed that the playing time and K-MMSE had a significant correlation, but it is very surprising that the relation disappeared when the group difference in game performance was analyzed with age and education as covariates. This suggests that the difference in playing time between groups can be sufficiently caused by demographic differences such as age and education, rather than being caused simply by cognitive impairment. In short, for screening MCI using serious games, we must calculate the effect of cognitive impairment on the games beyond the influence of demographic factors such as age and education. This requires a comprehensive approach that reflects various factors such as difficulty, reaction time (see, Tong, Chignell, Tierney, & Lee, 2016), and the number of errors, rather than just one factor.

5. CONCLUSIONS

The limitations of the standard pencil-and-paper diagnostic medical and psychological tests limit the ease with which they can be repeatedly applied to a large group of patients. Computer-based, serious games, on the other hand, permit low-cost, repetitive screening for MCI and, additionally, allow for investigation into various behavioral aspects that standard testing does not permit.

This study explored the possibility of screening MCI, an early stage of dementia, with serious games using various behavior data and relatively large size of sample. The experimental results showed the possibility that groups of general people and people with MCI can be distinguished based on various behavioral data obtained from the serious games. Furthermore, the results showed the significant correlation between game data and the score of K-MMSE.

Finally, serious game consists normally of two important components; functional and enjoyable. While the computer games developed in this study showed well the possibility of diagnostic tool as a functional component, the other component related to fun and motivation of the game is not taken into account for the study. More various and empirical researches about interaction between human and computer game including motivation, usability, engagement and so on will need to be accumulated to make game-based cognitive assessment not only accurate but also realistic and fun tests.

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Conflicts of Interest

There are no conflicts of interest.

Ethical Declaration

All study participants provided informed consent, and the study design was approved by the appropriate ethics review board.

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