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Development and Evaluation of a Computer Game Combining Physical and Cognitive Activities for the Elderly

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ABSTRACT This study develops a cognitive computer game system for the motor-cognitive dual-task training of the elderly. This system simultaneously combines musical rhythm games with exercises for cognitive training, while the exercises are designed to correlatively combine movements with the concept of acupressure points. Incorporating the concept of acupressure points can motivate participants to complete the exercises. The system has the features of being improvable and expandable based on modular design. The system framework is divided into three parts: first, the motion sensing controller (MSC) can detect a trainee's slapping motions during cognitive training; a variety of installation methods are designed to flexibly coordinate with a user's conditions, slapping motions and acupressure points for application. Next, the rhythm game is a set of games combining images and musical rhythms. Games can be developed to correspond with different cognitive skills; in this study, relevant games have been developed for cognitive skills like processing speed, short-term memory, working memory, divided attention, and inhibitory function. Finally, the cognitive skill evaluation (CSE) uses the cognitive computer games to evaluate the user's relevant cognitive skills. Sixteen healthy elderly people aged 65 or older are recruited for evaluation of the various modes and functions of this system. After four weeks of interventional training twice a week, the subjects' cognitive skills such as short-term memory, divided attention, and inhibitory function improved significantly, and their overall cognitive function assessed by the Montreal Cognitive Assessment (MoCA) are also found to have improved. On the user's feedback questionnaire, their self-evaluation of physical conditions, the difficulty levels of the games, and their continued willingness to use the system all receive good appraisals. It can be seen that the rhythmic cognitive computer games in combination with exercises as developed in this study is helpful and feasible for the cognitive training of the elderly.

INDEX TERMS Cognitive training, physical activity, computer game, rhythm game, short-term memory, divided attention, inhibitory function.

I. INTRODUCTION

With increasing life expectancy, the population of elderly people has also increased substantially [1]. The main cognitive functions of people include memory, attention, executive ability, language, judgment ability, etc. As they age, their cognitive function gradually declines [2], [3], thereby increasing the cost of medical treatment and nursing care.

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Rowe and Kahn [4] proposed the concept of successful aging, and emphasized avoiding disease and disability as much as possible, while maintaining a high degree of cognitive skills and physical function and actively participating in productive activities. The World Health Organization (WHO) [5] also proposed the concept of active aging in 2002 in the hope that people could be "optimizing opportunities for health, participation and security in order to enhance quality of life as people age". Recently, WHO promoted the concept of healthy aging" as the process of developing and maintaining the functional ability that enables well-being in old age'' [6]. Therefore, as the elderly population is gradually increasing, ensuring that they can achieve the recommendations of successful aging is a very important topic.

At present, many studies in cognitive neuroscience have confirmed that cognitive functions can be trained. Liberati *et al.* considered that the aim of cognitive training is to maintain the flexibility of the brain's cognitive mechanism factors by executing repeated practices of standardized cognitive tasks [7].

The Scaffolding Theory of Aging and Cognition (STAC) states that, in the process of cognitive aging, the cognitive functions of the brains of elderly people, such as processing speed, memory, and inhibitory function are declining faster, and that intervention through external activities can enable the elderly to continuously construct a compensatory cognitive scaffolding. In short, the brain fights physiological changes due to aging by shaping alternative neural circuits or scaffolds. Approaches such as learning new things, exercise, mental activity, and cognitive training perhaps increase cerebral activation promoting neuronal proliferation and increasing the cerebral metabolic rate, thereby allowing the brain to establish an effective cognitive scaffold, maintain certain cognitive functions, and slow down the rate of decline [8].

Compared with traditional cognitive training approaches, various technologies in recent years have also been applied to cognitive training [2], [9], [10]. Many of these studies have applied game-style and computer-based methods for cognitive training. The advantages of such methods are that users' motivation can be stimulated; participants' anxiety can be reduced, which would improve performance; the interface used can be equipped with more intuition and usability for the target group; and the possibility of long-term participation can be increased [11]. Combining the concepts of computerization and games, cognitive training can be more flexible and richer in content design and can be free from environmental constraints [12]. Therefore, in order to attract participants and maintain their interest in using it, researchers have applied the concept of games in cognitive training or developed it into games [13].

Chi *et al.* [14] developed a serious game called Smart Thinker, which aims to train memory, processing speed, color recognition, and attention span. There are four games in total in Smart Thinker: a coloring game (Color Game), a number game (High-Low), a graphic game (Rock Paper Scissors), and a word game (Find Me), in order to promote participants' cognitive skills such as attention and memory. The authors expressed that, after game training with Smart Thinker, the relevant cognitive skills of participants improved significantly.

A gift-purchasing serious game developed by López-Martínez *et al.* [12] provides training of executive functions for participating elders. In the game, participants need to purchase gifts under specified criteria and limited budgets, thereby training participants' planning skills and organizational skills needed to achieve a planning goal. The authors analyzed the collected data and concluded that games can increase motivation to participate and promote relevant cognitive skills.

In the study of Bruun-Pedersen *et al.* [15], virtual reality (VR) technology was applied to assist the elderly in physical therapy. The authors developed an audio-visual virtual environment (VE) augmentation for an exercise bike. In addition to the visual display, this system uses headphones to provide a soundscape for assistance. Postolache *et al.* [16] also applied VR technology to develop a serious game for rehabilitation and medical treatment of body and limbs.

Traditionally, aging is often accompanied by cognitive and motor deterioration. With the proposal of the concepts of successful aging, active aging and healthy aging, medical and research personnel have increasingly worked on developing different types of cognitive training to slow down this deterioration of the elderly.

With increased research investment, computer-game-based cognitive training has been demonstrated to have a positive impact on elderly people's cognitive skills, such as processing speed, attention, and memory [17]–[19]. Therefore, cognitive computer games have great potential in promoting the motor and cognitive skills of the elderly. However, most commercial video games like Xbox and Nintendo Wii may be too difficult for the elderly to engage and have limits on adjusting their levels of difficulty. Thus these commercial games could cause frustration to the player and limit the control of progression of the intervention [20], [21]. Geelen and Soons [22] evaluated the motivation of elderly people to participate, they considered that the perceived cost and inclination to remain sedentary are obstacles to their motivation to continuously use cognitive games. Thus, when studying and developing a cognitive training system, reducing the influence of these two factors is an important development strategy [23].

In the relevant studies of rehabilitation medicine, although motor functions will decline with increasing age, maintaining physical activity can slow the rate of decline, which shows that therapeutic exercise can help improve the motor functions of body and limbs [24], [25]. Churchill *et al.* also found that the results of tests of cognitive function are generally better for elderly people with a high level of physical activity in daily life [26]. Rahe *et al.* compared the effects of pure cognitive training with that in combination with exercise and discovered that different levels of motor control as required in cognitive training will influence the effects of cognitive training [27]. A study has shown that the combination of exercise and cognitive training should have a significant improvement on the reaction speed of the elderly [28].

The aim of this study was to develop a set of computer games simultaneously combining physical and cognitive training. In the feasibility testing stage, only the performance of participants in the game was adopted as the evaluation. In the formal test, the standard general cognitive function assessment as well as the game scores results were incorporated together for comparison.

II. MATERIALS AND METHODS

A. SYSTEM DESIGN

The system framework developed by this study is shown in Fig. 1. It consists of three main parts: a motion sensing controller (MSC), a rhythm game, and a cognitive skills evaluation (CSE). The MSC is used to sense the slapping motion of a participant during the game. The rhythm game is a set of cognitive training games and different games are designed for different cognitive skills, so that participants can engage in training of different cognitive skills. The CSE is used to evaluate the performance of the participants in the cognitive games; not only can it be used to evaluate the participants' relevant cognitive skills, but it can also provide immediate feedback on the scores as a reference for the participants and to stimulate their motivation to continue participating.

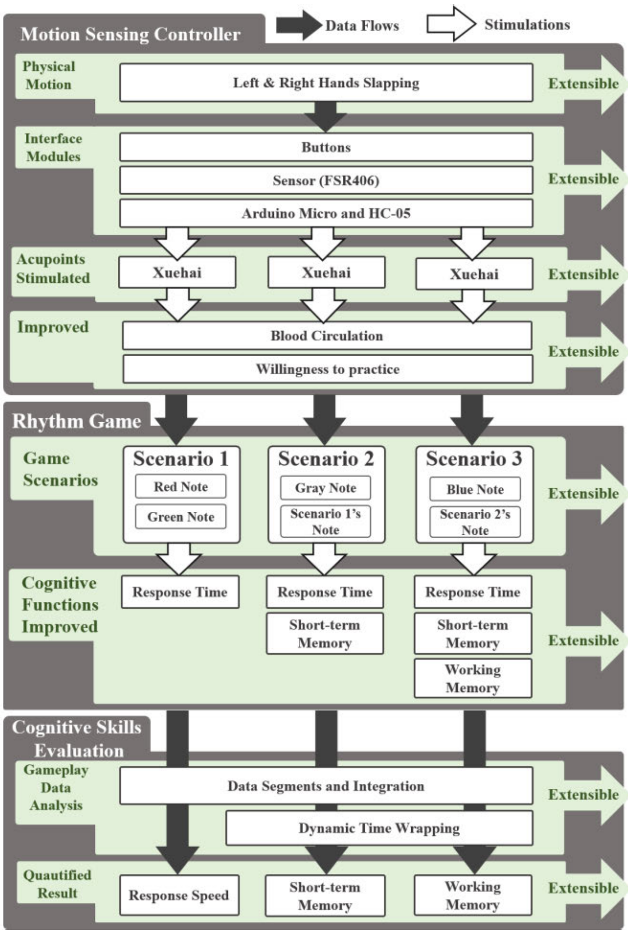

FIGURE 1. System framework.

A feature of this framework is modularization. Not only can the module itself be adjusted and improved, but it can also be expanded horizontally. For example, in the rhythm game module, different rhythm games can be added.

The basic game progress is shown in Fig. 2. The development concepts are broken down as below. First, it is expected to increase the sense of security and acceptance for the elderly people who use this game for training to increase their

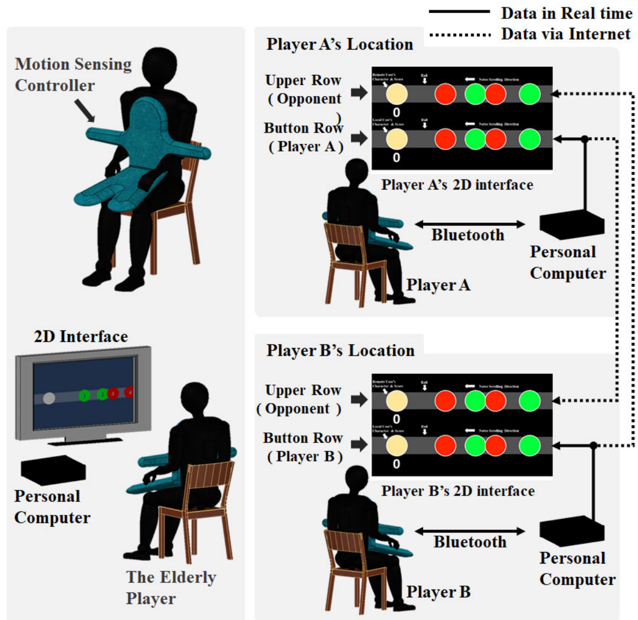

FIGURE 2. Game progress and strategy.

motivation to continue training. Therefore, the starting approach is to adopt a sitting posture (after becoming familiarized, the user can choose the standing position), and the MSC is installed in a bolster pillow for participants to use.

Second, to help the elderly be more willing to use this system, we have incorporated the concept of acupoints in Chinese medicine. A study by Yang *et al.* showed that the stimulation of acupuncture points can promote peripheral blood flow [29]. In Asia, especially in Taiwan and China, many elderly people are convinced of its curative effects, and this has spread to Western society and become popular in recent years [30]. The design of a slapping motion for the MSC not only takes account of the effect of physical activities, but also the installation of the MSC is selected to correspond with the acupoints possessing curative effects for acupressure in Chinese medicine. From a psychological viewpoint, the participating elderly people will be more convinced of the beneficial effect of the slapping motion, thereby increasing their willingness to continue practicing.

Third, this game combines the rhythm of music with the movement of circles on a screen. During the game, the participants can feel the changes in color and the rhythm of the music at the same time, so the content of cognitive training will become interesting and challenging.

Fourth, this system only needs a computer with the previously installed games and a bolster pillow installed with the MSC to proceed. It can easily coordinate with home audio-visual equipment, so the elderly can be training themselves in a familiar environment.

Fifth, the game with an interaction mechanism to provide an immediate feedback for the participants' performance. The game can display the scores from training in real time, so that participants can immediately observe their performance in training, and this can also increase participants' motivation to continue practicing by improving their scores. The game also has a two-player synchronization mode (see Fig. 2 and Fig. 3), allowing participants to practice or compete together.

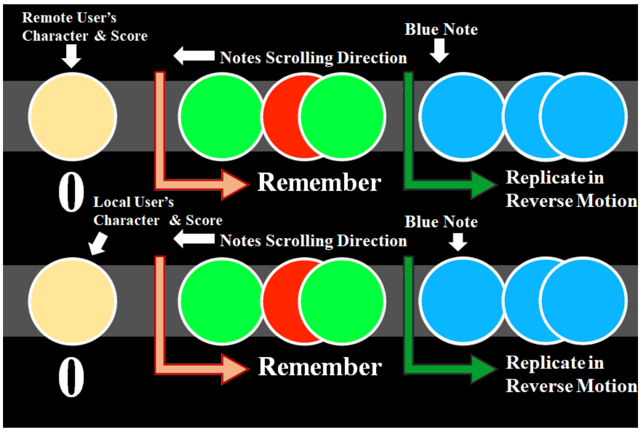

FIGURE 3. A game screen of the two-player mode.

1) THE MOTION SENSING CONTROLLER

The MSC allows participants to choose whether to press or slap the color inputs. An advantage is that it can be installed on the participant's body or on a table, ground, or other necessary surface, and it can be coordinated with the requirements of cognitive computer games to expand the number of inputs.

This MSC includes two main parts: a sensor and a controller.

FSR406 resistive pressure sensors are used as sensors to detect whether the button switch is pressed. The sensors are connected in series with a 10 kΩ resistor to ground, and the operating input voltage is 5 V. To let elderly participants clearly feel the tactile feedback and know whether they have successfully given an input, improve the quality of the gaming experience, and let participants actively use force when slapping the sensors to achieve the effect of exercise training, mechanical button switches are used.

The Arduino Micro microcontroller is selected as a controller and is paired with the HC-05 Bluetooth communication module for linkage with the computer host where the computer game system is installed, so that the signals detected will be translated back to the computer host.

The entire MSC is assembled with a shell made via 3D printing. In addition to the aforementioned sensor, microcontroller, and Bluetooth communication module, the necessary batteries and circuits are altogether incorporated (see Fig. 4).

The feasibility test showed that using 4 kHz sampling rate and 2.25 V as the threshold value for determination can effectively identify a participant's slapping motion with a time interval of more than 0.056 s every time (see Fig. 5).

A total of two MSCs were used in the feasibility test, and the installation positions on the human-shaped bolster pillow correspond to the acupoints, Xuehai, on the left and right knees. In the game, participants slap these two MSCs in a sitting posture while holding the human-shaped bolster pillow for training.

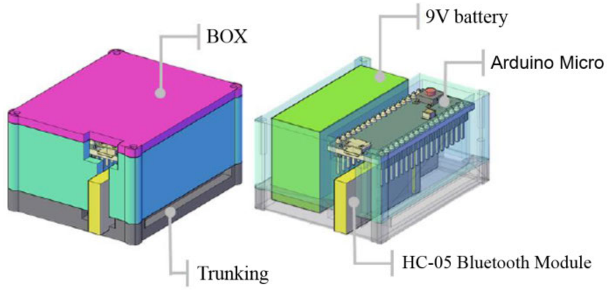

FIGURE 4. Motion sensing controller.

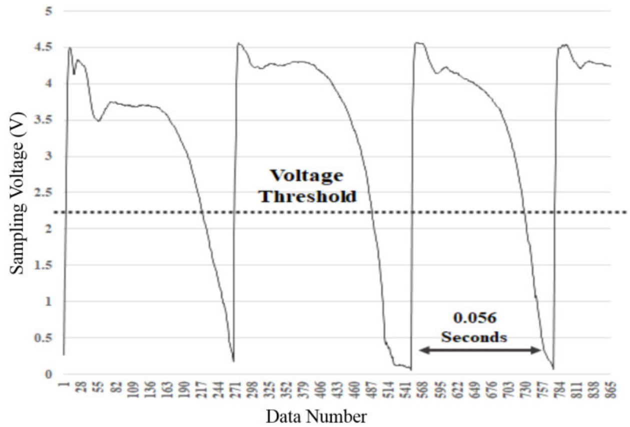

FIGURE 5. Voltage signals of slapping motions within 0.21s.

2) RHYTHM GAME

The musical rhythm game in the computer-game cognitive training system of this study is developed using the Unity game development software. Unity is a cross-platform 2D/3D game engine developed by Unity Technologies. It is completely free for personal use and rich in relevant resources. Coupled with its cross-platform characteristics, it is fairly easy to convert the developed software to other platforms in the future. This study was carried out on a general computer system, which will work as long as the computer has the Bluetooth communication function. The size of the display screen and the volume of the speakers used in the cognitive training process can be selected according to the participants and venues in practical operation. It can also be carried out just using a notebook computer.

The basic operating concept of the game is that participants need to face circles of different colors to remember and react. Circles in the middle of the screen will move horizontally from right to left. When the circle moves to a designated position, a participant needs to press the corresponding color button within a fixed amount of time. This is the triggerable range of slapping. The slapping is counted as effective when the circle is within this range. The color, number, and movement style and speed of the circle moving from right to left will vary depending on the difficulty of the game and the cognitive skills to be trained. The system will record and evaluate the time pressed by the participant, while the number at the bottom left is the real-time score of the current rhythm game (see Fig. 6).

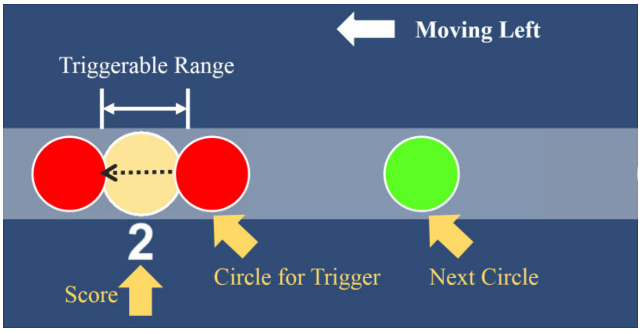

FIGURE 6. **Effective triggerable range.**

In the feasibility test, the MSCs for the left and right knees correspond respectively to the green and red circles moving on the screen. Three types of scenarios have been developed for participants to practice.

a: SCENARIO 1 (S1)

As shown in Fig. 6, a participant needs to input the color correctly for the circle moving from right to left on the screen when it enters the triggerable range, i.e., participant needs to correctly slap the corresponding MSC during the time when the circle is within the triggerable range. The gameplay is similar to Taiko no Tatsujin or Guitar Hero. This scenario is mainly intended to train the reaction speed of participants. The movement speed of the circles on the screen is divided into four difficulty levels. The initial level is 100 beats per minute (BPM), this increases by 50 BPM for each higher level, to a maximum of 200 BPM.

b: SCENARIO (S2)

In Scenario 2, the game begins with a short segment the same as in S1. At this point in time, the participant not only has to slap the colors of circles in sequence, but also has to remember the sequence of colors. When the moving circle turns gray, participants need to slap in the sequence of colors just learned. This is inspired by the Audio Ninja game. The main aim is to train participants' short-term memory. It is divided into six levels of difficulty according to the number of circles in the sequence of colors that need to be memorized. In Level 1, the colors of two circles must be memorized, and each higher level has one additional circle. At the highest level, the participant needs to memorize the sequence of colors of seven circles.

c: SCENARIO 3 (S3)

Compared with S1 and S2, S3 focuses on training participants' short-term memory and working memory. In this scenario, the circles moving from right to left have a total of four colors, namely red, green, gray, and blue. In the memory stage, the circle is red or green and the participant should slap with the S1 approach and remember the color sequence. When the circles turn gray or blue, the participant is instructed to slap the memorized sequence of colors of the circles. If gray circles appear, the gameplay will be exactly the same as in S2. Conversely, if blue circles are displayed, then left and right will be reversed when slapping following the remembered sequence of colors of circles, i.e., the button of the left knee must now be slapped for red circles and the button of the right knee must be slapped for green circles (Fig. 3 is a screenshot of the two-player mode in S3). The difficulty setting for this scenario is the same as that of S2; it is also divided into six levels.

3) COGNITIVE SKILLS EVALUATION

Although S1, S2, and S3 enhanced the required cognitive skills sequentially, the gameplay in later stages actually includes the gameplay of previous stages, so the score cannot directly reflect the cognitive skills as emphasized by the game. For example, in S2 and S3, the gameplay of their memory stages is the same as that of S1; the score in this part may be just the reaction speed score of the participant.

Taking the actual data of S3 in Fig. 7 as an example, the upper half shows the participant's slapping status; the horizontal axis indicates time; $+1$ and -1 on the vertical axis correspond to the left and right knees, respectively; and lower half shows the corresponding correct answers. From the text labels below the upper half of the diagram, we can clearly see that these segments of actual gameplay data are in fact switching between the scenarios of S1 and S3. The participant must memorize and slap simultaneously in the scenario of S1, and then use working memory in the scenario of S3 to recall the sequence of colors of the circles and perform slapping in a designated approach. Thus, the real S3 data should be deleting the part belonging to S1, thus giving Fig. 8. In the same way, we can also exclude the part belonging to S1 in the data of S2.

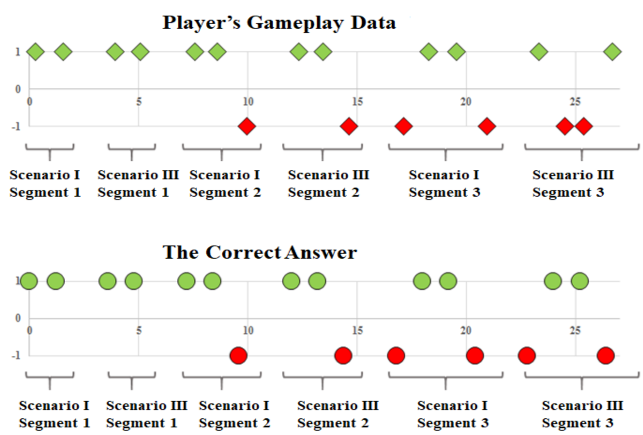

FIGURE 7. **Comparison of participant performance and correct answers for S3: (Top) participant's gameplay data and (Bottom) correct answers.**

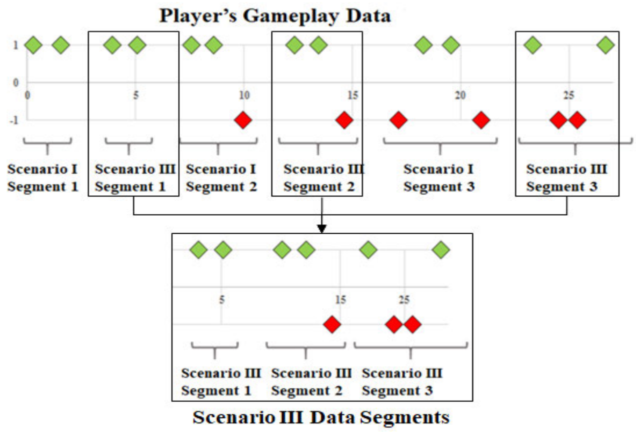

FIGURE 8. Comparison of participant performance and correct answers for S3, extracting the aspect of working memory.

However, in further analysis of this cognitive computer game, all the scores are based on multiple cognitive skills. Even if a participant has good short-term memory or working memory, to obtain a score in the game, he/she must slap within the correct time. This means that reaction speed, a cognitive skill, has influences on all scenarios.

B. FEASIBILITY TESTING

In the feasibility testing (Fig. 9), we invited eight healthy elderly people with ages between 65 and 93 years old to participate. After the explanation and trial play, the participating elderly people continuously complete the musical rhythm games of S1, S2, and S3. The performance of the participant was analyzed based on their scores. After the testing was completed, the participants were also asked to fill in a questionnaire to give feedback in order to evaluate the level of their acceptance of this system.

FIGURE 9. Operation of the game in feasibility testing.

Five young people under the age of 30 were invited as a control group to further evaluate the difficulty of the system.

C. MODIFICATION

After going through the feasibility testing, we continued to make improvements to the system. The main aim is to strengthen the correlation between the rhythm game and cognitive skills and enhance the richness and complexity of gameplay.

1) THE MOTION SENSING CONTROLLER

First, the aim is to increase the number of inputs (MSCs) and motions used in the cognitive games up to four. After changing to four inputs, the gameplay of the musical rhythm game can become more diverse. At the same time, the number of slapping motions that can be designed and the corresponding acupressure points are increased to four. At the same positions during feasibility testing, red and green still correspond to the participant's right knee and left knee, respectively. The newly added blue and yellow correspond to the participants' right shoulder and left shoulder, respectively. Compared with the original motion of slapping the right knee and left knee corresponding to the acupoints of Xuehai or the acupoints on the three Leg Yang Meridians, the newly added motion of slapping the right shoulder and left shoulder corresponding to the acupoints of JIAN JING increases the amount of activity, which can enhance the effect of exercise in cognitive training.

In order to help participants achieve an effective slapping motion, the determining voltage threshold for the MSCs was adjusted. After actual measurement, the output signals of the MSC sensors for heavy pressure (700 gw) and light pressure (70 gw) are 4 V and 2.5 V, respectively (see Fig. 10). In order to ensure the training effect of the slapping motions, the voltage threshold for determining a signal by pressing the MSC is set to increase to 3 V. At the same time, the sampling frequency is increased to 9600 Hz, so that the system can be more sensitive.

In the practice mode of the games, participants need to learn the magnitude of slapping strength required for completing the slapping motions in the training. After that, the game will formally start.

After trials with several elderly people, we improved the gameplay to be more diverse, so that the system can be suitable for use by elderly people with more conditions. The first is the signal input approach. A computer keyboard can also be used for operation as an aid for elderly people whose arms are not capable of gross motor skills can also use this system for cognitive training.

Furthermore, taking account of the differences in body shape and physical conditions of participants, the input methods have also been increased, in addition to the original bolster pillow, to be more convenient for participants to use. The newly added slapping points on the right shoulder and left shoulder require MSCs to be installed on the vest

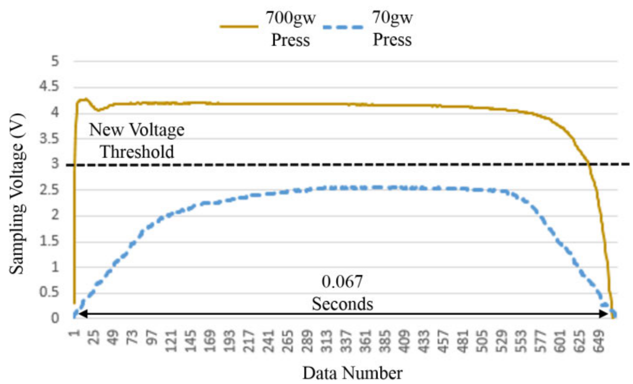

FIGURE 10. Signal difference in slapping strength.

(Fig. 11 and Fig. 12); the user can choose an appropriate sized vest according to their body shape. The MSCs on the knees have a newly added installation approach with hook-and-loop fasteners. This approach can even allow a therapist to design different slapping motions or choose different acupoints according to the physical condition of the participants. They can also be installed in suitable positions in coordination with the body shape of the participant, or in more practical positions for participants with less mobility. With this improvement, participants can also decide whether to adopt a sitting or standing posture to play the game according to their physical condition.

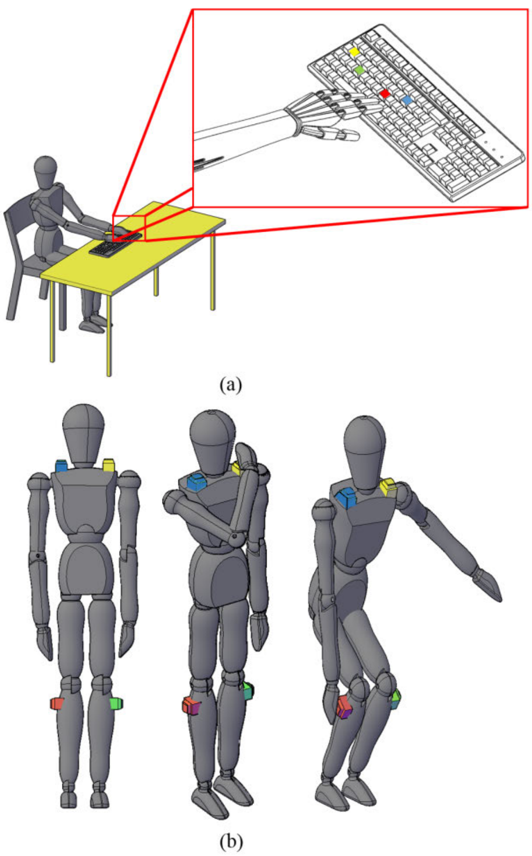

FIGURE 11. Operating interface devices: (a) fine-motor group use by pressing the colored keys on the keyboard and (b) gross-motor group use by slapping the buttons on the shoulders or knees.

FIGURE 12. Operation of the game by an elderly subject in the gross-motor group.

In addition, the MSCs can also be installed on a tabletop or the floor for addition or greater movements, so that the system can be more diverse in practical applications.

2) RHYTHM GAME

In the feasibility testing, we found that the scores of cognitive computer games are influenced by the same cognitive skills, such as reaction speed, because this is related to whether participants can slap their answers to the corresponding MSC within the triggerable time. Therefore, when we improved the cognitive computer system, the game's scrolling speed was selected to be 100 BMP based on the results of feasibility testing, in order to prevent the game speed causing stress to the elderly participants, thereby affecting their performance.

The S1 is mainly for training reaction speed. After improvement, this mode becomes a basic practice mode. Furthermore, the colors change from two colors to four colors, which increases the complexity of the game, so there is no need to exchange left and right hands, which is in order to prevent participants from forming habits or feeling bored with their motions.

Based on these improvements, we have newly developed three types of cognitive computer games. The corresponding cognitive functions are short-term memory, divided attention, and inhibitory function.

The practice mode originates from the S1. This mode is mainly for practicing reaction speed. When the colored circles appear sequentially and randomly on the screen and move horizontally from right to left into the effective triggerable range, participants merely need to press on the MSC of the corresponding color. This mode can help participants familiarize themselves with the method of playing this cognitive game and can also be used as a warm-up before cognitive training.

The main cognitive skill to be trained in Game 1 (G1) is short-term memory. Participants need to first memorize the colors and sequence of circles in the upper-left corner of the gaming screen. After the circles on the upper left have disappeared, a same number of gray circles moving horizontally from right to left will appear in the middle of the screen. When the gray circles successively move to the triggerable range, participants need to input the correct colors in sequence (see Fig. 13). If the tester performs well, then the number of circles will increase to raise difficulty of the game.

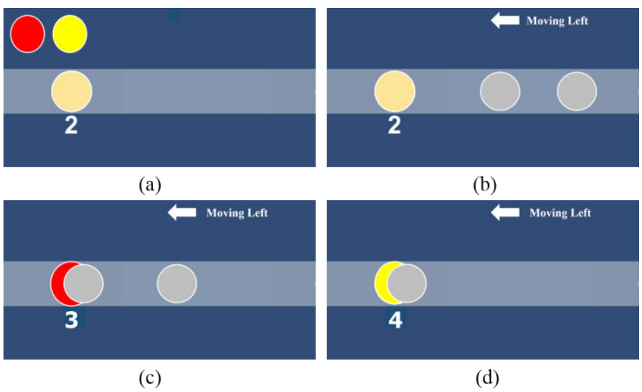

FIGURE 13. Game 1: (a) memorizing colored circles, (b) certain circles moving from right to left, (c) triggering the red sensor if a certain circle arrives in the circular beige region, (d) triggering the yellow sensor if a certain circle arrives in the beige region.

The main cognitive skill to be trained in Game 2 (G2) is divided attention. There will be consecutive numbers in the colored circle in the upper left corner of the game screen, and the numbers are the order of slapping. There will be the same number of gray circles moving horizontally from right to left in the middle of the screen. When the gray circles move to the triggerable range in sequence, participants need to enter their corresponding colors in the correct order (as shown in Fig. 14). In the same way, the number of circles will increase along with the raised difficulty of the game.

The cognitive skill to be trained in Game 3 (G3) is inhibitory function. There are two circles in the upper left corner of the screen of this game, corresponding to a red light and a green light; their function is similar to the red and green traffic lights and they are used to display the current state of the game. When the circles in the middle of the screen move close to the triggerable range, the red and green lights in the upper left corner will randomly light up. If it is a green light, then the corresponding color will need to be inputted; conversely, if it is a red light, then there will be no need to give an input (see Fig. 15).

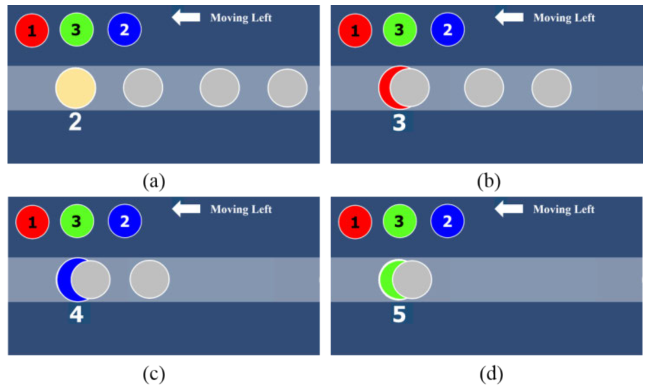

FIGURE 14. Game 2: (a) Color circles with consecutive numbers appear in the upper left, and the same number of gray circles move from right to left in the middle, (b) When the first gray circle enters the triggerable range, slap the first MSC corresponding color (red), (c) When the second gray circle enters the triggerable range, slap the MSC corresponding to the second color (blue), (d) When the third gray circle enters the triggerable range, slap the third MSC corresponding to color (green).

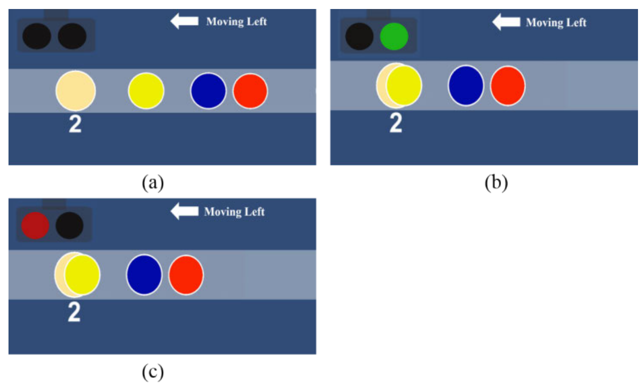

FIGURE 15. Game 3: (a) certain circles moving from right to left, (b) triggering the yellow sensor while the green light is on, and (c) not triggering the yellow sensor while the red light is on.

3) COGNITIVE SKILLS EVALUATION

Compared with the system at the time of feasibility testing, the musical rhythm games used in the improved system are G1, G2 and G3. These three games are mainly developed for a single cognitive evaluation

This study was review by the Research Ethics Committee of National Taiwan University Hospital. The Unique Protocol ID is 201804055RINC and the Official Title is "Efficacy of Computer-Based Cognitive Game Training on Motor and Cognitive Functions for Healthy Elderly". We used a historical control study design. By advertising publicly, we recruited and screened sixteen healthy elderly people to participate in the experiment. A flowchart detailing the process of evaluation testing is shown in Fig. 16. To test the various modes of this system, all the elderly people were first evaluated at the baseline stage, and then divided into a gross-motor group for slapping the MSC and a fine-motor group for operating the keyboard. The experiment was first conducted over a four-week period with no intervention, and then a pre-test was carried out to evaluate the conditions of the elderly

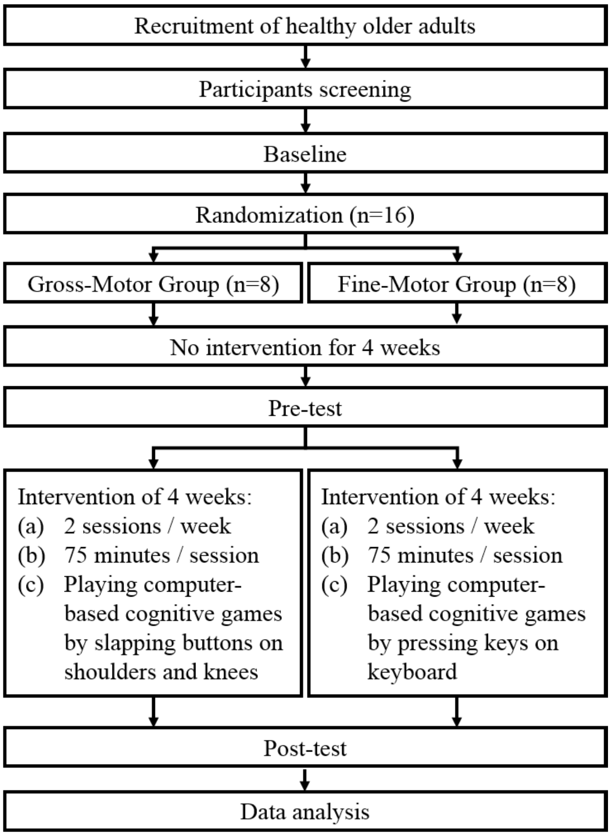

FIGURE 16. Flowchart of process of evaluation testing.

people again. This was followed by four weeks of separate intervention training, and finally a post-test evaluation was carried out.

4) PARTICIPANT

The inclusion criteria of the participants in this study are:

(1) Age ≥ 65 years old;

(2) MoCA score ≥ 18 [31];

(3) Are able to watch the screen and clearly hear the instructions with or without correction of vision and hearing;

(4) No obvious limitation of motor function of upper and lower extremities; and

(5) Are able to understand and abide by relevant instructions in training and testing.

The exclusion criteria are:

(1) Those who have injuries, fractures, or breathing problems;

(2) Those who have undergone surgery during the study period; and

(3) Having severe diseases related to cognitive function.

Sixteen participants screened and participated were recruited, and were randomly assigned into the gross-motor or the fine-motor group. The demographic and cognitive function are shown in Table 1. In this study, we combined the results of both groups as a whole and did not compare the results of two groups due to the small sample size.

TABLE 1. Demographic characteristics of the participants.

	GMG (*n* = 8)	FMG (*n* = 8)
Sex		
Female	3 (37.5%)	2 (25.0%)
Male	5 (62.5%)	6 (75.0%)
Age (years)	76.0 (82.8–67.0)	75.0 (80.0–68.8)
Education (years)	12.0 (14.0–12.0)	12.0 (12.0–9.0)
Religion		
Believer	7 (87.5%)	4 (50.0%)
No religion	1 (12.5%)	4 (50.0%)
Marital Status		
Single	0 (0.0%)	0 (0.0%)
Married	8 (100.0%)	6 (75.0%)
Widowed	0 (0.0%)	2 (25.0%)
Divorced	0 (0.0%)	0 (0.0%)
Vocational qualification		
Working	1 (12.5%)	1 (12.5%)
Retired	7 (87.5%)	7 (87.5%)
Chronic Illness		
Hypertension	3	4
Hyperlipidemia	0	2
Diabetes	0	2
Hypothyroidism	0	1
Melancholia	0	1
Autoimmune Disease	1	0
None	4	1
Living Status		
Living alone	1 (12.5%)	1 (12.5%)
Living with family	7 (87.5%)	7 (87.5%)
Economic Status		
Upper Class	0 (0.0%)	0 (0.0%)
Middle Class	7 (87.5%)	6 (75.0%)
Lower Middle Class	1 (12.5%)	2 (25.0%)
Lower Class	0 (0.0%)	0 (0.0%)
Exercise Regularly		
Yes	6 (75.0%)	6 (75.0%)
No	2 (25.0%)	2 (25.0%)
MoCA*	25.5 (27.0–23.5)	26.5 (28.0–21.5)

Note: Age, Education, and MoCA were presented as median values (IQR). GMG = gross-motor group; FMG = fine-motor group; MoCA = Montreal Cognitive Assessment.

5) EVALUATION APPROACH

In total, there are four types of evaluations conducted for all the participants in this study, i.e., cognitive function evaluation, motor functions evaluation, game evaluation, and feedback of participants via a questionnaire after completion of the testing evaluations. The breakdown is as follows.

a: COGNITIVE FUNCTION MEASURES

General cognitive function: The MoCA is an effective and reliable tool for overall cognitive assessment, which can effectively screen out mild cognitive impairment [32]. This method covers visuospatial skills naming, executive skills, concentration, memory (immediate and delayed), language, abstract concepts, and sense of orientation, etc. The total score is 30 points. A higher score means better cognitive skills.

Short-term memory: A forward Digit-Span Task (DS-forward) is a commonly used method to evaluate working memory, and its results have good reliability [33], [34]. This method has the subject repeat a set of numerical digits in order, with more added at increasing difficulty. The score indicates the maximum number of digits that the subject can memorize, with the maximum score being 10 points.

Divided attention: The Color Trails Test 2 (CTT-2) is a method to measure concentration, sequencing, and executive functions. It has good inter-rater reliability for the elderly [35]. The subject needs to link the numbers of different colors successively starting from 1 on the paper. The score is the time it takes for the subject to complete the test; a shorter time is better.

Inhibitory function: The Stroop Color and Word Test (SCWT) measures the inhibitory function and cognitive flexibility of subjects. Only the third part of Golden's version [36] is used in this study. Participants observe words printed in different colors of red, blue, or green and read aloud the print color of the word correctly. The score is the time it takes for the subjects to finish reading the printed colors of all words; a shorter time is also better.

b: MOTOR FUNCTIONS MEASURES

Upper limb: The Nine Hole Peg Test (NHPT) is a simple and fast way to evaluate finger dexterity and process speed; it has high inter-rater reliability and moderate test–retest reliability [37]. This measurement approach is performed for the right hand and left hand separately. The score is the time it takes to complete the operation; a shorter time is better.

Lower limb movement and balance: The get-up-and-go test (GUG) and the five-times sit-to-stand test (FTSST) are reliable and effective methods of evaluation of motor function and balance for the elderly [38], [39].

c: GAME EVALUATION

Game evaluation is conducted using the rhythm game developed by this study. In order to take care of the gross-motor group and fine-motor group at the same time, a seated operation approach different from that used during training was designed. Four MSCs are installed separately on the tabletop and the floor (see Fig. 17). The subject needs to use hands and feet to input signals. During game assessment, participants need to complete G1, G2, and G3 sequentially in order to evaluate three cognitive skills: short-term memory, divided attention, and inhibitory function.

d: QUESTIONNAIRE SURVEY

In this study, a questionnaire was designed for participants to fill in after the entire testing process had finished. The questions are mainly divided into three categories, i.e., participants' self-evaluation the performance after participating in the test, evaluation of the computer-game cognitive training system as developed by this study, and a survey of their willingness to use this system.

III. RESULTS AND DISCUSSION

A. EVALUATION RESULTS FROM BASELINE TO PRE-TEST

From the baseline to the pre-test, with no intervention in the cognitive computer games, there are few or no significant

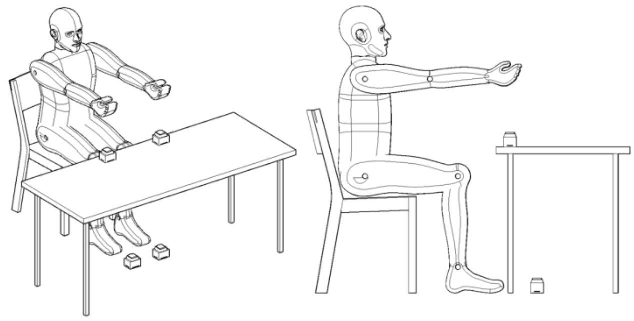

FIGURE 17. Operation for game evaluations.

differences in the changes in short-term memory, divided attention, inhibitory function, and motor function of the healthy elderly participants. The results indicated that there was no learning effects of the test measures. It can also be inferred that the elderly people who chose to participate in the experiment, apart from the fact that their health and other conditions met the requirements of the experiment, had physical conditions with a relatively stable status. Thus, they are suitable for intervention testing with the cognitive computer game in this study.

B. COGNITIVE COMPUTER GAME INTERVENTION

After four weeks of cognitive computer-game intervention, it can be shown that the improvements in all testing items reached significant levels, except for NHPT-R and HNPT-L (Table 2). The corresponding abilities of these two items are upper-limb motor skills of the right and left hands, respectively. Although there is no significant level of improvement, the time required for the testing is also slightly improved.

Next, the games developed in this study and their corresponding cognitive skills are analyzed. The corresponding cognitive skill of G1 is short-term memory; short-term memory can be tested using DS-forward. The P values of the tests for the scores of the two items between pre-test and post-test are 0.001 and 0.008, respectively, indicating that the short-term memory could improve significantly after training. The corresponding cognitive skill of G2 is divided attention. This testing item for cognitive skill can be tested using CCT-2. The P values of tests for the scores of the two are almost 0 and 0.007, respectively, also indicating that the divided attention improved significantly after training and the trends in the results of the two are in line. The corresponding cognitive skill of G3 is inhibitory function. This cognitive skill can be tested using SCWT. The P values of tests for the scores of the two items are 0.01 and 0.002, respectively; this shows that the results of the two are also in line. Again, comparing the MoCA testing results of overall cognitive function, the P value of a test for scores before and after intervention with cognitive computer games is 0.008, also indicating that the overall cognitive function of the elderly subjects could improve significantly.

In contrast, NHPT, GUG, and FTSST related to the physical functions, including body movement, limb movement,

TABLE 2. Results for baseline, pre-test, and post-test after intervention.

Variable	Baseline	Pre-test	Post-test
MoCA (point+)	25.56±0.318	26.00±02.68	27.94±01.57**
DS-forward (number+)	6.94±01.44	6.81±01.17	7.75±01.18**
CTT-2 (s-)	129.47±34.74	120.00±32.99	101.78±25.77**
SCWT (s-)	160.37±40.70	154.67±48.48	138.93±32.90**
NHPT-R (s-)	23.23±04.75	23.05±02.51	21.50±02.94
NHPT-L (s-)	23.67±02.82	24.48±03.47	23.27±03.28
GUG (s-)	09.92±01.33	09.99±01.45	9.16±01.20*
FTSST (s-)	12.36±03.57	1.59±02.93#	10.63±03.00*
G1 (%+)	63.47±15.09	67.78±14.40#	85.36±09.39***
G2 (%+)	60.16±13.71	65.88±15.90#	86.45±08.18***
G3 (%+)	80.92±17.19	89.13±14.32	98.38±02.01**

Note: #: $P < 0.05$ as compared to that at baseline; *: $P < 0.05$ as compared to that at pre-test; **: $P < 0.01$ as compared to that at pre-test; ***: $P < 0.001$ as compared to that at pre-test.
MoCA = Montreal Cognitive Assessment; DS-forward = forward Digit-Span Task; CCT-2 = Color Trails Test 2; SCWT = Stroop Color and Word Test; NHPT-R = Nine Hole Peg Test - Right hand; NHPT-L = Nine Hole Peg Test - Left hand; GUG = get-up-and-go test; FTSST = five-times sit-to-stand test; G1 = Game 1; G2 = Game 2; G3 = Game 3.

and balance control, showed no significant improvement after the training. It might be that the intensity or the duration of the training was not sufficient to induce the training effects.

C. COMPARISON OF GAME ASSESSMENT AND TRADITIONAL EVALUATION APPROACHES

During the feasibility testing, as the score of S3 was related to the cognitive skills of processing speed, short-term memory, and working memory, the analysis will be more complicated. S2 has a similar issue. Therefore, when improving the system, the game content is adjusted to be directly related to a single cognitive skill. For example, G2 is only related to divided attention, so that the analysis can be more easily carried out.

However, the biggest difference between the cognitive computer games we have developed and the standard cognitive skill testing is the so-called ''triggerable time'', i.e., subjects need to answer within a certain period, and an answer given beyond this time frame is invalid and the answer for the circle will immediately be deemed as wrong and it will proceed automatically to the next stage, i.e., the rhythm of the progress of testing is controlled by the system. In contrast, the standard cognitive skill test allows subjects to control the speed of progress of cognitive testing, and the speed of answering a certain question will not interfere with the answer to the next question. For example, in CTT-2, which tests divided attention, if subjects take a long time to find the number they are looking for, this will only prolong the total time taken to complete the test, and answers for the current number or the next number will not be barred.

Therefore, despite looking at only the overall test results, the computer game assessment results are in line with the trend of standard recognition evaluation results, and it is still impossible to infer that the computer game assessment approach can be equivalent to a standard cognitive evaluation. This requires more samples to conduct analysis and research.

The current scrolling speed of the games is set at 100 BPM based on the results of the feasibility testing. The reason for choosing this speed is that the difference between the elderly and the young participant is the smallest. The appropriate game speed can also be further studied to find suitable game speeds for participants with different ages or physical conditions, so that the effectiveness of cognitive training can be improved and the scores tested can be more representative.

D. QUESTIONNAIRE FEEDBACK

After the participants completed cognitive training using the system developed by this study, more than 75% of the participants considered that their own cognitive skills and their abilities to move their body and limbs in various ways had improved (Fig. 18 and Fig. 19). These self-perceived evaluation results are in line with the results of evaluations on the various domains of cognitive and physical function as conducted in this study. It can be seen that the benefits of cognitive training conducted using the system developed in this study were clearly felt by the participants. Being able to notice their own improvements can increase the motivation of the elderly to continue training.

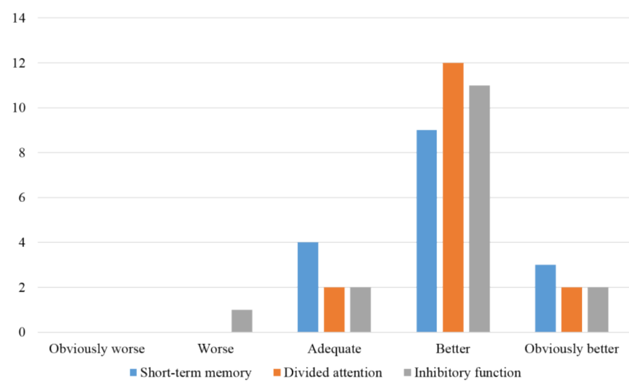

FIGURE 18. Participants' self-evaluation of cognitive skills after intervention with the cognitive computer games.

Most participants thought that the current system's difficulty settings, interface, and operation approach are appropriate or easy, which shows that the design of this system is suitable for the elderly

When surveyed for their feedback on their willingness to use the system, all participants expressed a willingness to participate in such training again (Fig. 20). Moreover, 93.75% of the participants are willing to recommend their relatives and friends to participate, and 81.25% of the participants are willing to buy this device.

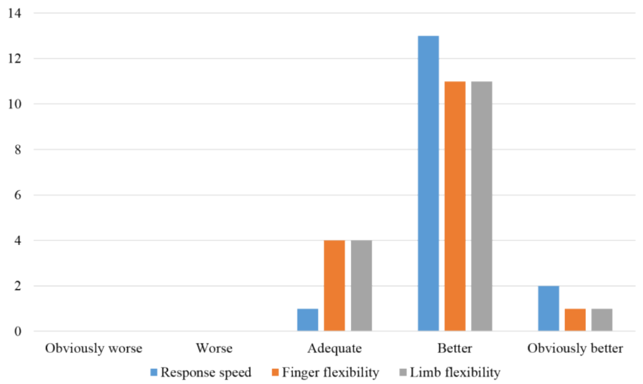

FIGURE 19. **Participants' self-evaluation of physical conditions after intervention with cognitive computer games.**

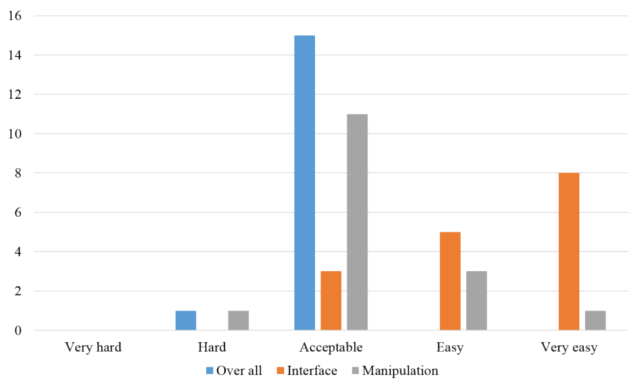

FIGURE 20. **Feedback of participants after intervention with the cognitive computer games.**

IV. CONCLUSION

Applying the motor-cognitive dual-task training computer games developed by the authors for the healthy elderly people can effectively improve their general cognitive function and specific cognitive skills, such as short-term memory, divided attention, and inhibitory function. This dual-task computer game training is helpful for improving these cognitive skills, but not for the physical function. Cognitive training computer games can be further developed to improve additional types of cognitive skills. Compare with cognitive games developed on game consoles, this system has the advancement of flexibility and expandability. The training program can be easily modified according to the participants' individual needs. The MSC we developed for this system can be installed in any locations, the therapist can design suitable movements for every elderly person based on his/her physical conditions. The healthy elderly people feedback positively on the use of the cognitive computer games developed in this study. All participants were enthusiastic to complete a four-week interventional training course that were executed twice a week, which shows that this is a feasible scheme for improving or maintaining cognitive functions of healthy elderly people. However, this study has the limitation of the small sample size. It is still necessary to conduct testing with more participants, in order to obtain a more comprehensive analysis and evaluation.

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