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How does it affect the willingness to continue rehabilitation training? A usability evaluation of a multi-sensory rehabilitation interactive game system (MRIGS) for older adults with mild dementia

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ABSTRACT

The prevalence of dementia is increasing every year, with one person developing dementia every 3 s. Therefore, this study proposes a novel multi-sensory rehabilitation interactive game system (MRIGS), which uses grip assistive devices combined with different colors and tactile stimulation to achieve multi-sensory training effects of vision, hearing, and touch. This study involved 17 older adults (72.2 years) with mild dementia (the MMSE between 17 and 23 points). To explore how the MRIGS affects their willingness to continue rehabilitation training, the system usability scale (SUS) with ten items was adopted to compare the differences between traditional multi-sensory rehabilitation (TMR) and MRIGS regarding gender, rehabilitation experience, and age.

The novel MRIGS interested older adults and improved their willingness for continuous rehabilitation. According to the overall SUS score, the MRIGS had better overall usability performance (86.18, being "*Good+*") than the TMR (66.62, only being "*Average-*") ($t = -4.44$, $p = 0.00 < 0.05$). In addition, the result shows that the MRIGS was a promising way to improve seven (out of 10) usability items (*Willingness*, *Convenience*, *Stress*, *etc.*) compared to TMR. For males, the MRIGS had better usability in "*Willingness,*" "*Convenience,*" and "*Difficulty,*" while "*Consistency*" was better for females. We also found a significant difference in "*Willingness*" for those with previous rehabilitation experience because they had experienced the difficulties and boring feelings encountered in TMR in medical institutions. On the contrary, the MRIGS could make rehabilitation more exciting and motivating. For those over 70, the MRIGS performed better in "*Convenience*" and "*Consistency,*" indicating that improving the overall convenience of training operations had become more important along with their natural decline of physical functions by aging. In addition, among older adults with weak grip strength in their dominant hand, the hand grip strength significantly influences their willingness to use the novel MRIGS.

The MRIGS developed in this study could integrate multi-sensory training to help older adults with mild dementia improve their motivation and willingness to continue rehabilitation training.

1. Introduction

In recent years, the global prevalence of dementia has been on the rise, with the disease becoming increasingly common among older adults. Sarcopenia is linked to dementia, as older adults with sarcopenia symptoms are more likely to experience cognitive decline, increasing their risk of developing dementia [1]. Sarcopenia is a significant syndrome affecting older adults, marked by a progressive loss of muscle

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mass and a decline in muscle function. It is clearly defined by hand grip strength, with males exhibiting strength below 28 kg and females below 18 kg [2,3]. Muscles and the nervous system are closely intertwined, and epidemiological studies have confirmed a positive correlation between grip strength and cognitive decline, making it a key indicator for evaluating dementia in clinical pathology [4].

The prevalence of dementia is known to increase with age, particularly for those over 70 [5–7]. About 3 % of people aged 70 to 74 are diagnosed with dementia, which increases to 22 % for those aged 85 to 89, and 33 % for those over 90. Thus, age is the strongest risk factor for dementia [8]. Unfortunately, there is currently no effective drug treatment for dementia. Nonetheless, human-computer technology has emerged as a leading intervention in the non-drug treatment of dementia, providing an effective training tool that can significantly improve the quality of life, physiological functions, cognition, and communication abilities of older adults with dementia ([9–11]; Chiu et al., 2023; [12]).

As individuals age, their multi-sensory perception functions begin to decline, which can lead to accelerated cognitive aging. The multi-sensory function score ranges from 0 to 12 points, based on quartiles of assessed sensory capabilities: vision (0–3 points), hearing (0–3), smell (0–3), and touch (0–3). Each score is summed for a total. A total score of 0 indicates excellent sensory function across all senses, while a total score of 12 signifies significant deficiencies in every sense [13]. Individuals with low multi-sensory function scores have a significantly higher risk of developing dementia, approximately twice that of the average person. Additionally, multi-sensory impairments have a higher risk of dementia, up to three times higher than those without sensory impairments, and twice as likely as those with a single sensory impairment [13,14].

Given these findings, it is crucial for older adults to engage in sensory integration training. While such training has traditionally focused on motor function, it is now understood that attention must also be paid to the critical relationship between sensation and movement. One example of sensory integration training used in clinical practice is multi-sensory therapy [15]. When integrated into care activities, multi-sensory treatment can have positive effects on women's reproductive adaptation, chronic mental illness patients, and dementia patients with cognitive dysfunction [15–17]. By increasing sensory input, multi-sensory therapy can indirectly affect the central nervous system, reduce electroencephalogram irregularities, and achieve relaxation, thereby effectively improving mood, behavioral functions, and quality of life [18,19]. Multi-sensory therapy can also promote an active senior lifestyle, as it can enhance physiological functions such as heart rate and blood oxygen saturation, as well as attention, memory, and standing balance, thereby reducing the risk of falls in older adults [20,21].

The Traditional Multi-sensory Rehabilitation (TMR) uses stages to train cognitive and muscle strength tasks, thus providing sensory stimulation. However, the TMR is not easy to attract older adults to use actively because repetitive movements and training lack interactive experience [22]. Therefore, how to attract them to train actively and continue training for a long time is an important issue. In other words, how does it affect their willingness to continue rehabilitation training? Will the operation of rehabilitation training affect their willingness? [23]. As mentioned above, gender and age are crucial factors for dementia, alongside the impact of training experiences and hand grip strength. Therefore, it's essential to explore how factors such as gender, age, previous rehabilitation experiences, and/or hand grip strength would affect their willingness to continue rehabilitation training.

To answer these questions addressed above, we have developed a Multi-sensory Rehabilitation Interactive Game System (MRIGS) that uses the nostalgic and retro music game scene to arouse the resonance of older adults, stimulate memory, and improve recall [24]. The MRIGS has combined the multi-sensory interaction of grip strength training with different-colored holding aids and tactile stimulation to achieve the vision, hearing, and touch training effects [25]. Moreover, the System Usability Scale (SUS) is adopted to explore the usability analysis of MRIGS and TMR, respectively [26,27]. The SUS, developed by Brooke in 1996, helps evaluate subjective perceptions and willingness of system usability after operation [24,28].

2. Materials and methods

This study would explore the usability of MRIGS (and TMR) for older adults with mild dementia [11]. This section would introduce how the MRIGS was developed and how the usability experiment was conducted.

2.1. Development of the multi-sensory rehabilitation interactive game system (MRIGS)

This study examined the Geriatric Department of National Cheng Kung University Hospital (NCKUH) and found they implemented multi-sensory cognitive stimulation designs throughout the environment. In this study, the 1960s scene design of the MRIGS (Fig. 1(a)) used retro vinyl records, along with nostalgic music (Fig. 1(b)), to arouse the resonance of older adults. To evoke special memories of the 1960s, enjoyable games with a nostalgic charm were created to enhance visual and auditory sensory stimulation [24,29]. Older adults used grip assistive devices with both hands (Fig. 1(c)) and employed interactive multi-sensory pressure sensing technology to control the interactive game. The cognitive training was further enhanced through different colored (red and blue) grip aids and various grip tactile aids (such as smooth and little protruding balls) designed to improve hand muscle strength training [12]. These aids were used as multi-sensory cognitive stimulation (including vision, hearing, and touch), improving training effectiveness and preventing degenerative phenomena in older adults.

This study used the pressure-sensing module to measure changes in hand pressure [30]. Once the sensing unit measured the signal, it was amplified and processed by the amplifying unit before being sent to the host for real-time display on the computer. The relevant signals were stored in the host and sent to the interactive game terminal. The interactive game was developed using Unity 3D cross-platform software, incorporating ICT software and hardware to create a JAVA underlying API suite for hardware connection. This allowed users to interact between the interactive game and rehabilitation aids [11,12], providing comfortable and safe hand grip strength training (as shown in Fig. 2).

The interactive game began by opening the game homepage (Fig. 3(a)), followed by entering the game (Fig. 3(b)). During the interactive game, older adults could control record playback by pressing the grip wearable device of the corresponding color according to the color of the randomly dropped vinyl record. If it were blue, they would push the blue smooth grip ball. Otherwise, the red protruding grip ball would be pressed (as shown in Fig. 1(c)). Completing the challenge within the allotted time frame was successful for older adults. Once the interactive game concluded, a feedback message would appear on the screen (Fig. 3(c)). Simultaneously, the interactive game would provide feedback on the player's training results (Fig. 3(d)), which could help professionals and physicians assess the muscle training status of older adults.

2.2. The usability experiment of MRIGS (and TMR)

The SUS could provide a degree of usability and satisfaction, allowing product designers (or system developers) to evaluate the usability of products (or systems) quickly [26].

2.2.1. Participants

This study involved 17 participants (nine males and eight females) with an average age of 72.2 years (ranging from 60 to 91). Seven (four males and three females) of them had no previous rehabilitation experience, and ten (five males and five females) had undergone rehabilitation. They were referred from Tainan Meiyou Nursing Home and Tainan North District Community Activity Center. This study utilized

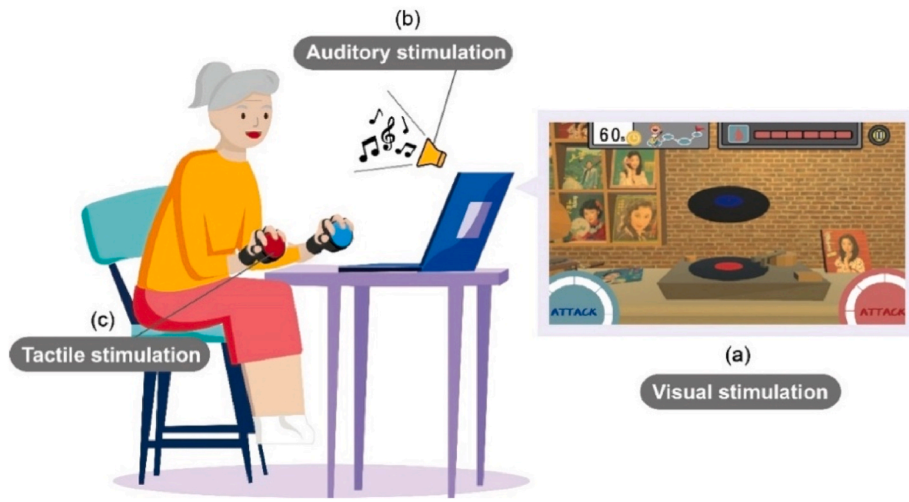

Fig. 1. The illustration of MRIGS, including (a) visual stimulation, a nostalgic design with retro vinyl records in the 1960s Taiwan; (b) auditory stimulation, playing with nostalgic music of the 1960s; and (c) tactile stimulation, various grip tactile aids, e.g., smooth or little protruding balls.

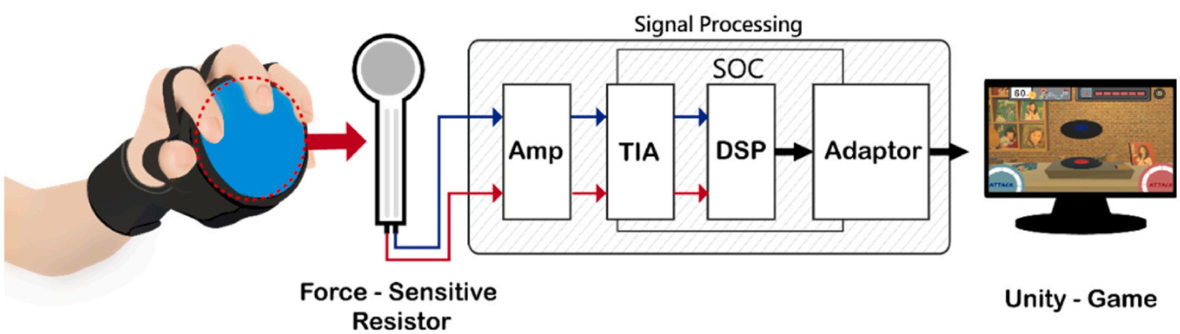

Fig. 2. The software and hardware serial connection flow chart of the MRIGS.

the Mini-Mental State Examination (MMSE), first introduced by Folstein in 1975, that has been validated and is commonly used in clinical practice and research to assess the progression of dementia [13,31–33]. It serves as an effective screening tool for cognitive impairment in older adults, systematically evaluating their cognitive function and mental status [34]. The MMSE consists of 11 questions assessing five cognitive function areas: Orientation, Registration, Attention and Calculation, Recall, and Language [31,34]. The total score is 30, with scores below 24 indicating mild cognitive impairment (MCI) and below 16 reflecting severe cognitive dysfunction [13,34]. For this study, older adults with MMSE scores ranging from 17 to 23 points were selected as experimental participants. After the interactive game rehabilitation training, they could cooperate with the researchers' instructions and were given a SUS evaluation.

2.2.2. The experimental procedure

The experiment had two parts. It involved cognitive training on grip strength and card color matching as TMR and MRIGS were designed in visual, auditory, and tactile environments. Each participant completed two experiments in a randomized sequence, and Fig. 4 shows the experimental procedure.

(A) TMR (the traditional multi-sensory rehabilitation)

The TMR experiment was conducted in two parts. The first part involved grip strength training using grip balls (with different tactile stimulation) and nostalgic music (Fig. 5(a)). The second part involved cognitive training using a color-matching activity. The rehabilitation training environment was comfortable, with chairs and nostalgic music (Fig. 5(b)). The participants exercised their hands by holding a strength ball at a high-frequency speed for 3 min. After the hand exercise, colored cards were placed on the table, and the participants had to turn over two cards at a time to find a matching pair [11]. The rehabilitation training ended once all the cards were recovered, which usually took about 3 min (as shown in Fig. 5).

Finally, the participants filled out the SUS evaluation with a five-point scale for 5 min. The SUS was adopted to collect older adults' subjective perceptions on 10 items (such as *Willingness*, *Complexity*, *Convenience*, *Stress*, *Integration*, *Inconsistency*, *Learnability*, *Cumbersomeness*, *Confidence*, *Difficulty*, etc.) about products (or systems) [11,22,28]. For example, older adults would be asked, "*I thought that I would like to use this TMR/MRIGS frequently*," for Item 1, "*Willingness*," as shown in Table 1. A brief rest period was then taken before commencing with the MRIGS training.

(B) MRIGS (the multi-sensory rehabilitation interactive game system)

Before commencing the MRIGS rehabilitation training, the researchers assisted the participants in wearing gripping and multi-sensory rehabilitation aids on both hands (as shown in Fig. 6). They provided verbal instructions on the interactive game operation and ensured comprehension by guiding the participants through one or two practice runs, which typically lasted around 3 min. Subsequently, the participants used grip wearable assistive devices on both hands to control the interactive game and engage in 3-min rehabilitation training. Ultimately, the participants completed the SUS evaluation in 5 min and had a short rest for the other training if needed (Please refer to Supplementary Fig. S1 for understanding the experiment's details.).

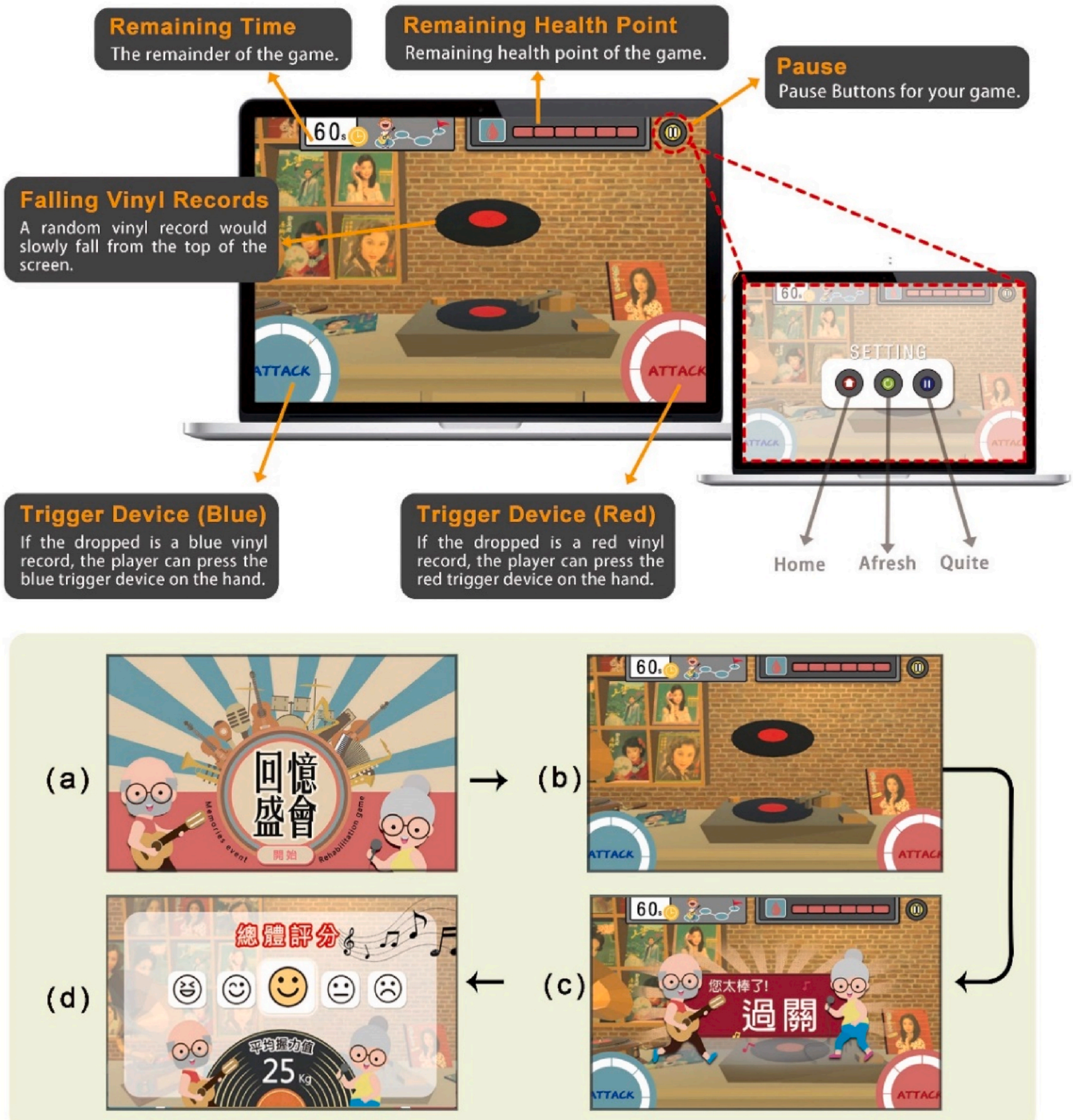

Fig. 3. The interactive game interface, (a) the game homepage, (b) the game scene, (c) the successful completion of the game, and (d) the feedback of training results.

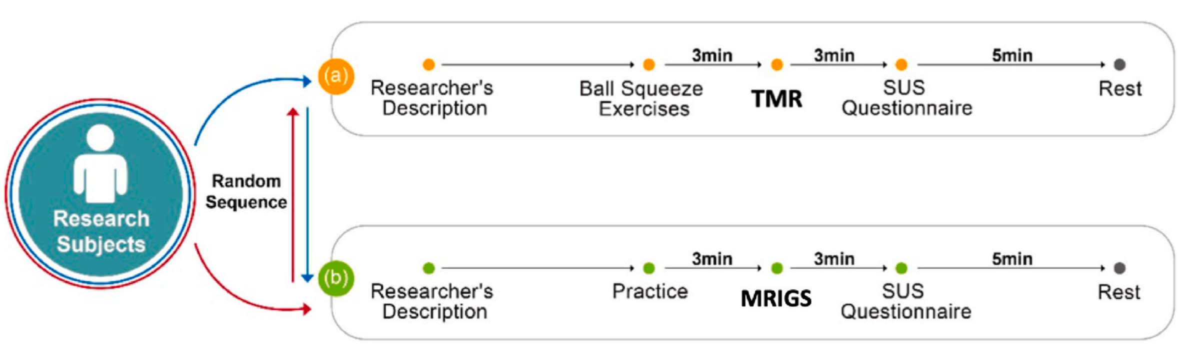

Fig. 4. The experimental procedure of TMR and MRIGS.

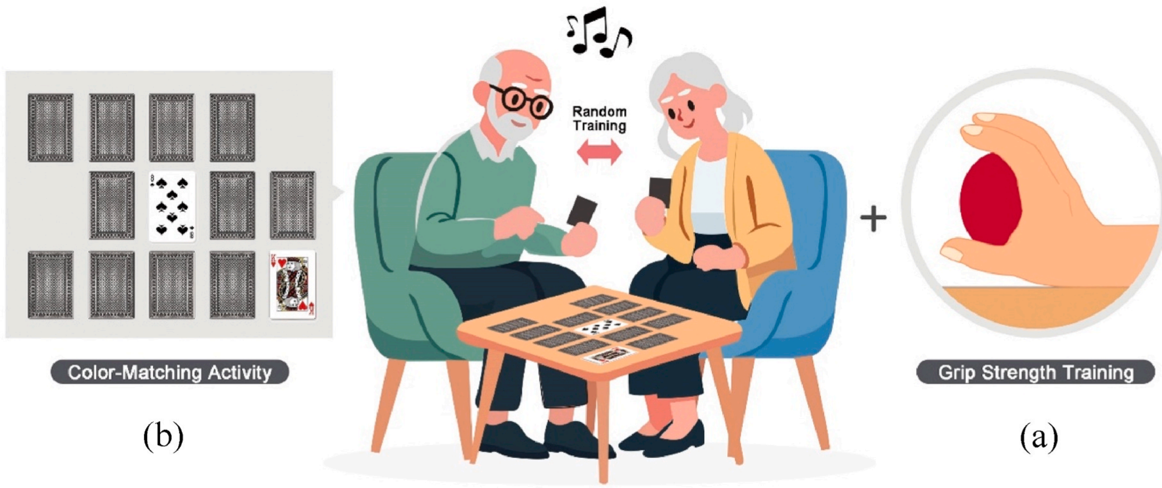

Fig. 5. The illustration of TMR, including (a) the grip strength training and nostalgic music; (b) a color-matching activity.

Table 1
SUS questionnaire design.

Item	Question description
1. *Willingness*	I thought that I would like to use this *TMR/MRIGS* frequently.
2. *Complexity*	I found the *TMR/MRIGS* unnecessarily complex.
3. *Convenience*	I thought the *TMR/MRIGS* was easy to use.
4. *Stress*	I thought that I would need the support of a technical person to be able to use this *TMR/MRIGS*.
5. *Integration*	I found the various functions in this *TMR/MRIGS* were well integrated.
6. *Inconsistency*	I thought there was too much inconsistency in this *TMR/MRIGS*.
7. *Learnability*	I would imagine that most people would learn to use this *TMR/MRIGS* very quickly.
8. *Cumbersomeness*	I found the *TMR/MRIGS* very cumbersome to use.
9. *Confidence*	I felt very confident using the *TMR/MRIGS*.
10. *Difficulty*	I needed to learn a lot of things before I could get going with this *TMR/MRIGS*.

Fig. 6. Before the MRIGS training, the researcher helped participants practice for 3 min.

3. Results

This study explored how the TMR and MRIGS affected the rehabilitation training of older adults with mild dementia. As mentioned in the Introduction section, gender and age are significant factors in dementia, along with previous rehabilitation experiences and hand grip strength. Understanding how these factors influence their motivation to continue rehabilitation training is crucial. Through SUS evaluations, we utilized the *t*-test to compare the differences between TMR and MRIGS regarding gender, rehabilitation experience, age, and hand grip strength. Table 2 shows the results of the SUS evaluations.

Table 2 shows that the overall SUS score for the TMR is 66.62, while the MRIGS is 86.18 ($t = -4.44$, $p < 0.00$). The result shows that the MRIGS has better overall usability performance (*Good*+) than the TMR (*Average*-) [11,35].

To further investigate, Table 3 shows the individual item benchmarks [35,36] for the TMR and the MRIGS. For the TMR, only three items (out of 10 items) achieved the "*Good*" level of the benchmark (Items 4, 5, and 8), and the worst items, 7, 9, and 10, just were only "*Poor.*" It shows there was a lot of room for improvement in the usability of the TMR. On the other hand, all 10 items of the MRIGS have reached the "*Good*" level (eight items being "*Good*+," and only two items being "*Good*-.") The result indicates that the MRIGS, as compared to the TMR, has a better user experience for older adults with MCI when interpreting single items from the SUS. In the following sub-sections, the effects of gender, rehabilitation experience, and age will be further analyzed to explore the details of TMR and MRIGS.

3.1. *The analysis of TMR and MRIGS*

The *t*-test analysis explored whether significant differences existed between TMR and MRIGS regarding 10 usability items. From Table 4, seven significant differences existed in "*Willingness*" (*I1*, $t = -3.20$, $p = 0.00$), "*Convenience*" (*I3*, $t = -2.39$, $p = 0.02$), "*Stress*" (*I4*, $t = 2.06$, $p = 0.04$), "*Inconsistency*" (*I6*, $t = 2.41$, $p = 0.02$), "*Learnability*" (*I7*, $t = -7.38$, $p = 0.00$), "*Confidence*" (*I9*, $t = -4.34$, $p = 0.00$), and "*Difficulty*" (*I10*, $t = 4.07$, $p = 0.00$). The results show that the MRIGS was a promising way to improve these usability items (*Willingness*, *Convenience*, *Stress*, *etc.*) compared to TMR.

Table 2
The overall SUS scores for the TMR and MRIGS ($t = -4.44$, $p = 0.00 < 0.05$).

Participant	Gender	MMSE	Rehab Experience	Age	Hand Grip Strength (Handedness)	TMR	M(SD)/n = 17	MRIGS	M(SD)/n = 17
1	Male	23	No	76	29.2	40.0	**66.62 (13.40)**	80.0	**86.18** (12.28)**
2	Male	21	Yes	66	25.1	62.5	***Average -***	75.0	***Good*** +
3	Male	20	Yes	60	24.5 *	77.5		87.5	
4	Male	20	Yes	64	17.5 *	52.5		80.0	
5	Male	21	Yes	77	26.7	70.0		75.0	
6	Male	22	Yes	74	21.8 *	57.5		97.5	
7	Male	21	No	66	27.6	62.5		90.0	
8	Male	23	No	81	21.5	62.5		90.0	
9	Male	19	No	73	19.7 *	92.5		100.0	
10	Female	20	No	69	12.5 *	62.5		72.5	
11	Female	18	Yes	69	12.2 *	47.5		87.5	
12	Female	18	Yes	69	12.9 *	75.0		100.0	
13	Female	19	Yes	91	17.8	67.5		100.0	
14	Female	21	No	73	18.2	65.0		57.5	
15	Female	22	No	74	16.8	75.0		95.0	
16	Female	20	Yes	74	10.6 *	75.0		100.0	
17	Female	23	Yes	71	17.5	87.5		77.5	

(* indicates participants with *WEAK* grip strength (handedness). Please refer to the Supplementary Table S1 for details.).
(**$t = -4.44$, $p = 0.00 < 0.05$).

3.2. Effects of gender

Was there any difference in the willingness to use TMR and MRIGS by gender? Table 5(a) shows that there were significant differences in "*Learnability*" (*I7*, $t = -5.25$, $p = 0.00$ for males; $t = -5.65$, $p = 0.00$ for females) and "*Confidence*" (*I9*, $t = -3.62$, $p = 0.00$ for males; $t = -2.52$, $p = 0.02$ for females), indicating that the MRIGS, which integrated multiple training contents, was equally effective for both male and female older adults in terms of improving their confidence and ease of learning during rehabilitation training. However, male older adults expressed concerns that these two rehabilitation ways were significantly different in "*Willingness*" (*I1*, $t = -2.67$, $p = 0.02$), "*Convenience*" (*I3*, $t = -2.74$, $p = 0.01$), and "*Difficulty*" (*I10*, $t = 4.16$, $p = 0.00$). Therefore, the MRIGS was better than the TMR for male older adults in "*Willingness*," "*Convenience*," and "*Difficulty*." Female older adults considered the MRIGS to have better "*Consistency*" than TMR (*I6*, $t = 2.68$, $p = 0.02$). Further analysis will be discussed in the Discussion section.

3.3. Effects of rehabilitation experience

To determine the impact of older adults with previous rehabilitation experience (i.e., TMR), we conducted the *t*-test analysis of these two rehabilitation ways. In other words, we also wanted to know whether previous rehabilitation experience would affect the willingness to use the novel rehabilitation training (i.e., MRIGS). From Table 5(b), no matter who had previous rehabilitation experience or not, there were significant differences in "*Learnability*" (*I7*, $t = -5.54$, $p = 0.00$ (with); $t = -4.59$, $p = 0.00$ (without)), "*Confidence*" (*I9*, $t = -3.56$, $p = 0.00$ (with); $t = -2.36$, $p = 0.03$ (without)), and "*Difficulty*" (*I10*, $t = 3.15$, $p = 0.01$ (with); $t = 2.41$, $p = 0.03$ (without)). This result also echoes Section 3.2. Regardless of "gender" and "rehabilitation experience" factors, MRIGS could integrate multi-sensory rehabilitation training to help older adults understand the rehabilitation goals, improving their motivation and performance. However, we also found a significant difference in "*Willingness*" (*I1*, $t = -2.74$, $p = 0.01$) for older adults with rehabilitation experience. In contrast, those without rehabilitation experience had a higher score of 4.70 on the MRIGS (than TMR being 3.60), but did not reach significance. It is worth further discussion and is presented in the Discussion section.

3.4. Effects of age

Table 5(c) shows that there were significant differences in "*Learnability*" (*I7*, $t = -5.54$, $p = 0.00$ for those aged 60 to 69; $t = -4.89$, $p = 0.00$ for those over 70), and "*Confidence*" (*I9*, $t = -3.17$, $p = 0.00$ (aged 60 to 69); $t = -3.08$, $p = 0.00$ (over 70)). The result is in line with the previous section: "The MRIGS could help older adults understand the rehabilitation content and goals, thereby improving their rehabilitation motivation and performance." In addition, for those aged 60 to 69, *I1* (*Willingness*), *I4* (*Stress*), and *I10* (*Difficulty*) had significant differences (*I1*, $t = -3.11$, $p = 0.00$; *I4*, $t = 2.44$, $p = 0.03$; *I10*, $t = 4.40$, $p = 0.00$), while *I3* (*Convenience*) and *I6* (*Inconsistency*) existed significant differences (*I3*, $t = -2.60$, $p = 0.01$; *I6*, $t = 2.21$, $p = 0.04$) for those over 70 years old. The results are also worth further discussion (in the Discussion section).

3.5. Effects of hand grip strength

Does the strength of the dominant hand grip affect the willingness to continue rehabilitation training? The handgrip dynamometer is used to measure the participants' dominant hand grip strength and can track improvements during rehabilitation [2,37]. Table 5(d) shows that no matter whether the participant's dominant hand grip strength is normal or weak, there were significant differences in "*Learnability*" (*I7*, $t = -4.87$, $p = 0.00$ (normal); $t = -5.86$, $p = 0.00$ (weak)), "*Confidence*" (*I9*, $t = -2.72$, $p = 0.02$ (normal); $t = -3.42$, $p = 0.00$ (weak)), and "*Difficulty*" (*I10*, $t = 2.95$, $p = 0.01$ (normal); $t = 2.81$, $p = 0.01$ (weak)). The result is in line with Section 3.3, "Effects of rehabilitation experience". It is interesting to dive deeply into the discussion. In addition, for those with normal hand grip strength, *I3* (*Convenience*) and *I8* (*Cumbersomeness*) had significant differences (*I3*, $t = -2.12$, $p = 0.05$; *I8*, $t = -2.11$, $p = 0.05$), while *I1* (*Willingness*) and *I6* (*Inconsistency*) existed significant differences (*I1*, $t = -2.55$, $p = 0.02$; *I6*, $t = 2.69$, $p = 0.02$) for those with weak strength.

4. Discussion

As compared the traditional rehabilitation training (TMR) and the novel rehabilitation training (MRIGS) in terms of gender, rehabilitation experience, age, and hand grip strength, the MRIGS is better than TMR in "*Willingness*" (*I1)* for older adults with rehabilitation experience, meaning that they are more willing to use it. It is supposed that those with rehabilitation experience have experienced the difficulties and boring feelings encountered in traditional multi-sensory rehabilitation activities in medical institutions. Therefore, the novel MRIGS could make rehabilitation training more exciting and thus increase the motivation for long-term continuous use through interactive game rehabilitation training. In addition, the "*Difficulty*" (*I10)* of MRIGS is lower than that of TMR, indicating that the MRIGS integrated gamified rehabilitation content with wearable devices is not difficult for older adults with

Table 3
The descriptive statistics of TMR and MRIGS based on the SUS evaluations.

SUS Item	Gender		Rehab Experience		Age		Hand Grip Strength (Handedness)		Item Benchmark			
	Male M(SD)/n=9 / *Female M(SD)/n=8*		*No Rehab Experience M(SD)/n=7* / *Prior Rehab Experience M(SD)/n=10*		*60-69 M(SD)/n=7* / *70 Above M(SD)/n=10*		*Normal M(SD)/n=9* / *Weak M(SD)/n=8*		TMR		MRIGS	
	TMR	MRIGS	TMR	MRIGS	TMR	MRIGS	TMR	MRIGS	*M(SD) n=17*	Bench.	*M(SD) n=17*	Bench.
1. *Willingness*	3.44 (1.01)	4.56 (0.73)	3.60 (1.07)	4.70 (0.67)	3.28 (0.76)	4.57 (0.78)	3.56 (0.83)	4.33 (0.82)	3.53 (1.01)	***Average +***	4.53 (0.79)	***Good +***
	3.62 (1.06)	4.50 (0.93)	3.43 (0.98)	4.29 (0.95)	3.70 (1.15)	4.50 (0.85)	3.50 (1.12)	4.75 (0.66)				
2. *Complexity*	2.00 (0.71)	1.44 (0.73)	1.90 (0.74)	1.60 (0.84)	2.43 (0.53)	1.71 (0.76)	2.00 (0.67)	1.78 (0.92)	2.06 (0.75)	***Average +***	1.65 (0.86)	***Good +***
	2.13 (0.83)	1.88 (0.99)	2.29 (0.76)	1.71 (0.95)	1.80 (0.79)	1.60 (0.97)	2.13 (0.78)	1.50 (0.71)				
3. *Convenience*	3.77 (0.67)	4.67 (0.71)	3.80 (1.03)	4.50 (0.71)	3.57 (0.97)	4.14 (0.89)	3.89 (0.57)	4.56 (0.68)	3.88 (0.86)	***Average +***	4.53 (0.71)	***Good +***
	4.00 (1.07)	4.38 (0.74)	4.00 (0.58)	4.57 (0.79)	4.10 (0.74)	4.80 (0.42)	3.88 (1.05)	4.50 (0.71)				
4. *Stress*	1.56 (0.73)	1.11 (0.33)	1.50 (0.53)	1.10 (0.32)	1.71 (0.49)	1.14 (0.38)	1.44 (0.68)	1.11 (0.31)	1.47 (0.62)	***Good***	1.12 (0.33)	***Good +***
	1.37 (0.52)	1.13 (0.35)	1.43 (0.79)	1.14 (0.38)	1.30 (0.67)	1.10 (0.32)	1.50 (0.50)	1.13 (0.33)				
5. *Integration*	4.56 (0.53)	3.89 (1.05)	4.10 (1.19)	4.10 (0.99)	4.29 (0.49)	3.57 (1.13)	4.22 (1.23)	3.56 (1.07)	4.35 (0.99)	***Good +***	3.88 (1.17)	***Good -***
	4.13 (1.36)	3.88 (1.35)	4.71 (0.49)	3.57 (1.39)	4.40 (1.26)	4.10 (1.19)	4.50 (0.50)	4.25 (1.09)				
6. *Inconsistency*	2.11 (1.27)	1.67 (0.50)	2.10 (0.99)	1.40 (0.51)	2.00 (1.00)	1.57 (0.53)	2.11 (1.10)	1.67 (0.67)	2.24 (1.03)	***Average***	1.53 (0.62)	***Good +***
	2.38 (0.74)	1.38 (0.74)	2.43 (1.13)	1.71 (0.76)	2.40 (1.07)	1.50 (0.71)	2.38 (0.86)	1.38 (0.48)				
7. *Learnability*	2.11 (1.05)	4.33 (0.71)	2.50 (0.97)	4.60 (0.69)	2.29 (0.95)	4.57 (0.53)	2.22 (1.03)	4.33 (0.67)	2.41 (1.01)	***Poor -***	4.53 (0.62)	***Good +***
	2.75 (0.89)	4.75 (0.46)	2.29 (1.11)	4.43 (0.53)	2.50 (1.08)	4.50 (0.71)	2.63 (0.86)	4.75 (0.43)				
8. *Cumbersomeness*	1.22 (0.44)	2.11 (1.45)	1.20 (0.42)	2.00 (1.41)	1.57 (0.79)	2.14 (1.57)	1.11 (0.31)	1.89 (0.99)	1.29 (0.59)	***Good +***	1.82 (1.23)	***Good -***
	1.38 (0.74)	1.50 (0.92)	1.42 (0.78)	1.57 (0.98)	1.10 (0.32)	1.60 (0.97)	1.50 (0.71)	1.75 (1.39)				
9. *Confidence*	2.44 (1.59)	4.56 (0.73)	2.90 (1.52)	4.70 (0.48)	3.14 (1.21)	4.71 (0.49)	2.78 (1.47)	4.33 (0.67)	2.88 (1.49)	***Poor -***	4.59 (0.62)	***Good +***
	3.38 (1.30)	4.62 (0.52)	2.86 (1.57)	4.42 (0.78)	2.70 (1.70)	4.50 (0.71)	3.00 (1.41)	4.88 (0.33)				
10. *Difficulty*	3.77 (1.72)	1.22 (0.67)	3.30 (1.77)	1.30 (0.95)	3.71 (1.49)	1.14 (0.38)	3.67 (1.41)	1.78 (1.13)	3.35 (1.65)	***Poor -***	1.47 (0.94)	***Good +***
	2.88 (1.55)	1.75 (1.16)	3.43 (1.62)	1.71 (0.95)	3.10 (1.79)	1.70 (1.16)	3.00 (1.73)	1.13 (0.33)				

Table 4
The *t*-test result of TMR and MRIGS.

SUS Item		Difference of Mean	*t* value	*p* value
1	*Willingness*	−1.00	−3.20	**0.00***
2	*Complexity*	0.41	1.49	0.15
3	*Convenience*	−0.65	−2.39	**0.02***
4	*Stress*	0.35	2.06	**0.04***
5	*Integration*	0.47	1.26	0.21
6	*Inconsistency*	0.71	2.41	**0.02***
7	*Learnability*	−2.12	−7.38	**0.00***
8	*Cumbersomeness*	−0.53	−1.59	0.12
9	*Confidence*	−1.71	−4.34	**0.00***
10	*Difficulty*	1.88	4.07	**0.00***

dementia to operate. It also echoes the result in "*Complexity*" (*I2)* that there are no significant differences in terms of gender, rehabilitation experience, age, and hand grip strength, thus meaning that the "*Complexity*" of MRIGS is the same as that of TMR. In other words, the interactive operation of MRIGS that introduces new technology will not make older adults feel (more) complicated. These results also prove that MRIGS is a welfare technology product and that it is crucial for older adults to continue using it [24,38].

These results also show that the MRIGS is developed through a nostalgic game design that can resonate highly with older adults, especially those aged 60 to 69. This is because the 1960s were the golden age of vinyl record pop culture in Taiwan. The rise of campus ballads combined with TV drama theme songs has become a catchy, youthful memory for those aged 60 to 69. In comparison, the TMR repeats the (boring) assessment training content and increases learning difficulty and operational convenience, reducing the motivation of older adults to continue using it. Moreover, for those over 70 years old, the MRIGS performs better in "Convenience" (I3) and "Inconsistency" (I6), indicating that their natural decline of physical functions by aging, improving the overall convenience of training operations becomes more critical in their willingness to continue rehabilitation.

In this study, we use the *t*-test to investigate gender, rehabilitation experience, and age factors, and further analyze the hand grip strength effect, which is a physiological indicator rather than just general factors. The results suggest that hand grip strength, whether strong or weak, significantly influences the willingness to continue rehabilitation training, particularly among older adults with weak grip strength in their dominant hand. Furthermore, this finding aligns with the "previous rehabilitation experience," which is worth further investigation in future experiments or studies. It also raises an interesting question: why do "hand grip strength" and "previous rehabilitation experience" have similar outcomes? One reasonable explanation is that individuals with prior rehabilitation experience may have sustained injuries or experienced weakened muscle strength or related symptoms. That is why hand grip strength is also a good indicator of overall body strength, and is commonly used in fitness tests [2].

Not only does the MRIGS resonate with older adults, but it also allows them to increase the fun of their rehabilitation during rehabilitation training, especially for female older adults who express that integrating various training content through gamification makes them more willing to continue using it. The MRIGS also uses different colors for visual cognitive training and grip assistive devices (with different tactile stimulation) for interactive games, which could improve the willingness and motivation to rehabilitate continually. After the usability experiment, some of their (qualitative) responses are listed as follows:

> *"After training, I feel increased blood circulation in my hands and significantly improved flexibility throughout my hands."*

> *"I will continue using it because it makes me feel more accomplished the more I play."*

Table 5
The *t*-test results in terms of gender, rehabilitation experience, age, and hand grip strength.

(a) The *t*-test result of gender

SUS Item	Male	Female
	TMR v.s MRIGS	TMR v.s MRIGS
	t value/*p* value	*t* value/*p* value
1. *Willingness*	**−2.67/0.02***	−1.75/0.10
2. *Complexity*	1.64/0.12	0.54/0.59
3. *Convenience*	**−2.74/0.01***	−0.81/0.42
4. *Stress*	1.66/0.11	1.12/0.27
5. *Integration*	1.69/0.11	0.36/0.72
6. *Inconsistency*	0.97/0.34	**2.68/0.02***
7. *Learnability*	**−5.25/0.00***	**−5.65/0.00***
8. *Cumbersomeness*	−1.75/0.09	−0.29/0.77
9. *Confidence*	**−3.62/0.00***	**−2.52/0.02***
10. *Difficulty*	**4.16/0.00***	1.63/0.12

(b) The *t*-test result of rehabilitation experience

SUS Item	Previous Rehab Experience	No Rehab Experience
	TMR v.s MRIGS	TMR v.s MRIGS
	t value/*p* value	*t* value/*p* value
1. *Willingness*	**−2.74/0.01***	−1.66/0.12
2. *Complexity*	0.84/0.40	1.24/0.24
3. *Convenience*	5.21/0.09	−1.54/0.15
4. *Stress*	2.05/0.05	0.86/0.40
5. *Integration*	0.00/1.00	2.04/0.06
6. *Inconsistency*	1.97/0.06	1.38/0.19
7. *Learnability*	**−5.54/0.00***	**−4.59/0.00***
8. *Cumbersomeness*	−1.71/0.10	−0.30/0.76
9. *Confidence*	**−3.56/0.00***	**−2.36/0.03***
10. *Difficulty*	**3.15/0.01***	**2.41/0.03***

(c) The *t*-test result of age

SUS Item	60–69 years	70 years and above
	TMR v.s MRIGS	TMR v.s MRIGS
	t value/*p* value	*t* value/*p* value
1. *Willingness*	**−3.11/0.00***	−1.75/0.09
2. *Complexity*	2.04/0.06	0.50/0.61
3. *Convenience*	−1.13/0.28	**−2.60/0.01***
4. *Stress*	**2.44/0.03***	0.84/0.41
5. *Integration*	1.53/0.15	0.54/0.59
6. *Inconsistency*	1.00/0.34	**2.21/0.04***
7. *Learnability*	**−5.54/0.00***	**−4.89/0.00***
8. *Cumbersomeness*	−0.85/0.41	−1.55/0.14
9. *Confidence*	**−3.17/0.00***	**−3.08/0.00***
10. *Difficulty*	**4.40/0.00***	2.07/0.06

(d) The *t*-test result of hand grip strength

SUS Item	Normal	Weak
	TMR v.s MRIGS	TMR v.s MRIGS
	t value/*p* value	*t* value/*p* value
1. *Willingness*	−1.89/0.08	**−2.55/0.02***
2. *Complexity*	0.55/0.59	1.57/0.14
3. *Convenience*	**−2.12/0.05***	−1.30/0.21
4. *Stress*	1.25/0.23	1.66/0.12
5. *Integration*	1.16/0.26	0.55/0.59
6. *Inconsistency*	0.98/0.34	**2.69/0.02***
7. *Learnability*	**−4.87/0.00***	**−5.86/0.00***
8. *Cumbersomeness*	**−2.11/0.05***	−0.42/0.68
9. *Confidence*	**−2.72/0.02***	**−3.42/0.00***
10. *Difficulty*	**2.95/0.01***	**2.81/0.01***

"After exercising at home, you can assess your training progress without needing to go to the hospital, which is very convenient."

"Many old vinyl records in the interactive game are hard to find nowadays. I remember one record being viral."

Compared with traditional training, the MRIGS is more highly learnable besides having higher integration. It could quickly make older adults with mild dementia understand the training content through game training and improve their rehabilitation performance.

5. Limitations and future research

This study has made significant progress, but there is always room for improvement. First, we only conducted the usability evaluation and didn't follow up over a more extended period (such as a clinical trial for eight weeks, 12 weeks, six months, or longer). Future research could be conducted to explore the long-term effects of our findings in more depth. Second, this study has primarily focused on assessing the system's usability using the SUS questionnaire. Still, future research could expand testing to include physiological measurements, such as grip strength, reaction time, error times, and MRI tests for a more comprehensive approach. This comprehensive approach would provide a more robust validation of our study findings.

Moreover, the cognitive training could be integrated into the interactive game content, which could be more diverse. Cognitive training employs various methods to improve cognitive abilities and skills, such as memory, attention, problem-solving, language, and spatial reasoning. For example, adding the attention element with the vibration intensity, memory feedback, and/or sound-light effects with the problem-solving content can enhance interaction fun and increase game stickiness, thus further evaluating the effects of visual, auditory, tactile, or other senses' stimulation on willingness. Finally, in this study, we selected 17 older adults with mild dementia (comprising nine males and eight females, with MMSE scores ranging from 17 to 23 points) as participants. However, in future research, recruiting more participants would allow for the formation of additional subgroups, enabling a more comprehensive and in-depth analysis of various factors. This could provide valuable insights to enhance motivation for older adults engaged in active rehabilitation training.

6. Conclusion

The study has developed the Multi-sensory Rehabilitation Interactive Game System (MRIGS) that integrates nostalgic games with multi-sensory rehabilitation content, utilizing physiological sensing technology and tactile stimulation. The MRIGS aims to make rehabilitation more engaging for older adults, increasing their motivation and willingness to continue rehabilitation, which is crucial. The system incorporates visual stimulation with strong color contrast and a voice guidance system to enhance usability and reduce operational errors. The MRIGS has received positive feedback, as it does not elicit negative emotions during rehabilitation training. These findings offer valuable insights for future multi-sensory rehabilitation game development.

CRediT authorship contribution statement

Chien-Hsiang Chang: Visualization, Methodology, Data curation, Writing – original draft, Software, Conceptualization, Resources, Investigation. **Chun-Chun Wei:** Visualization, Resources, Data curation, Project administration, Software, Conceptualization. **Wei-Chih Lien:** Resources, Validation, Investigation, Supervision. **Lenka Lhotská:** Validation, Resources, Supervision, Formal analysis. **Josef Cernohorsky:** Supervision, Resources, Software. **Yang-Cheng Lin:** Validation, Software, Methodology, Data curation, Writing – original draft, Funding acquisition, Conceptualization, Writing – review & editing, Supervision, Resources, Investigation, Formal analysis.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Yang-Cheng Lin reports financial support was provided by National Science and Technology Council of Taiwan. Yang-Cheng Lin reports a relationship with National Science and Technology Council of Taiwan that includes: funding grants. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.compbiomed.2025.111020.

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