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On The 3D VR Simulated Rubik's Cube Game for Smart Pads

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Abstract: In this study, interface designs of a VR 3D-simulated Rubik's Cube game were developed and evaluated. A 2 × 2 × 2 mixed-design ANOVA was executed, with age (younger adult/older adult), interface (arrow/intuitive), and task complexity (easy, a single symmetrical task/difficult, a bio-symmetrical task) experimental design. The first three factors were between-subject designs while the latter was a within-subject design. The dependent variable was the percentage of the task performance and wayfinding questionnaire. The collected experimental data were analyzed by regression method to clarify the correlation among age, interface, task complexity, and wayfinding strategy. There were 96 subjects in the experiment, including 48 younger adults (aged from 18~22) and 48 older adults (aged from 60~85). The experimental results and statistical analysis showed that the task difficulty had a significant effect on task performance in the 3D VR Rubik's Cube game. For the smart pad, the arrow interface was significantly more effective than the intuitive interface. The theoretical model regression analysis of the task complexity, interface, and wayfinding strategy was shown to be significant. Results showed that users may be affected either positively or negatively by the wayfinding strategy, as a higher score on familiarity indicates better VR game task performance, whereas for the usual spatial behavior wayfinding strategy, the opposite result was found for memory. These results can be used to assess VR game interface designs, taking into consideration age difference, task complexity, experiential self-report on 3D VR games, and including VR rotation navigational

Keywords: VR; game; interface design; age; task complexity; Rubik's Cube

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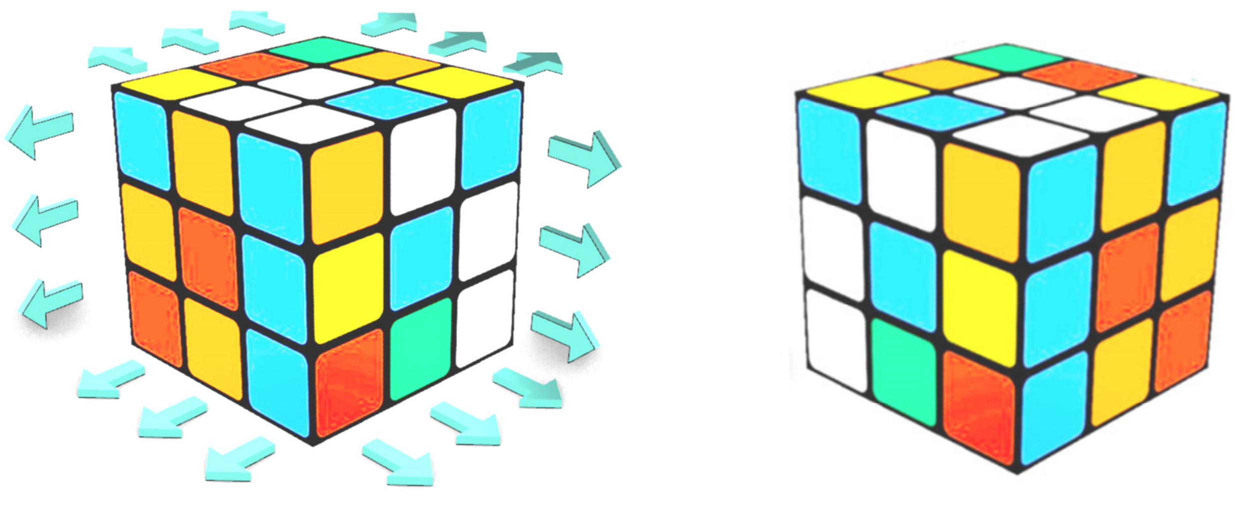
1. Introduction

Rubik's Cube has been honored as a "Magic Cube"; it is a well-designed 3D symmetrical combination puzzle toy that won the Outstanding Contributions to Science Education Award in 2010 [1]. This toy was invented in 1974 by Ernő Rubik and is a best-selling toy, with more than a billion people owning one [2,3]. As previous studies [4–6] have claimed that a Rubik's Cube game would benefit the development of human beings' spatial symmetrical capability, it would be considered a healthy choice for a smart pad game design.

It is important to note that the interactive design or interface will have a crucial effect on the quality and performance of the smart pad application (app) [7–9]. A problematic interface may affect the performance of the 3D VR game, and consequently, addressing interface issues before the evaluation of a 3D VR game is crucial. As many types of interfaces have been proposed and designed, the comparison among interfaces is a fundamental issue before the decision regarding the best choice. Based on the collection and analysis of the current online Rubik's Cube games, there are two main categories: arrow and intuitive (Figure 1). The arrow interface type was designed to label the direction arrow beside the edge of the simulative model; the user can touch the arrow or slide on the arrow using a finger to activate the rotation. In the intuitive design, unlike the arrow type, no direction arrow is labeled, and users may slide the model intuitively. As Chang and Huang [10] have demonstrated with a 3D VR Rubik's Cube game on a computer, the main effects of gender and control device were significant. However, interactive effects among the other possible variables such as age and interface design remain undiscovered.



(**a**) (**b**)

Figure 1. The VR 3D Rubik's Cube and real model. (**a**) Arrow icon-controlled Rubik's Cube. (**b**) Intuitive Rubik's Cube.

Other previous studies had also identified that the individual difference in spatial capacity was considered the core factor that would affect VR operation performance. The term wayfinding strategy means the ability to find a way to a particular location and to recognize the target when approaching it [11,12]. It is also considered to be related to knowledge such as cognitive map (overall spatial comprehension), sense of direction (route knowledge), memory (survey knowledge), and familiarity. Additionally, age was also found to be one of the most potent factors to trigger individual spatial differences [13]. A previous study has further shown the cognitive-related responses which vary with age while using VR [14,15]. There are numerous solutions available on the smart pad that can assist older adults in their daily living activities. However, these solutions are sometimes not welcomed in the older adult community due to usability and accessibility factors. Although VR technology on smart pads is not novel, little is known about the use of this technology by older adult populations [16].

Among diverse methods for measuring navigation performance [17–19], some studies have claimed that correction and time spent on mental processing are key to interpreting the relationships between sense of direction and wayfinding strategy. In Takeuchi's study (1992), there were two principal factors (Factor I—awareness of orientation, Factor II—memory for usual spatial behavior). A questionnaire, "SDQ-S (Sense of Direction Questionnaire-Short Form)," consisting of 20 items was proposed and successfully tested. It was noted from the pilot test that the task with a difficult level was not possible to be completed within a reasonable time (within 30 min), especially for most of the older adult group. In the present study, an average time limit was set for each of the task complexity levels, and the percentage of the task completion of the VR game task and the Sense of Direction Scale [20] were applied to verify how wayfinding strategies affect task performance in virtual environments (VE).

To sum up, we developed and evaluated interface designs of the VR (virtual reality) 3D-simulated Rubik's Cube game. Using a smart pad gaming app, we carried out an experiment on the differences between interface designs concerning age, gender, and task complexity (easy and difficult), as well as sense of direction. The study results and related suggestions are given. It is expected that the study results can benefit VR interface design and research for the aged.

The following specific results were hypothesized:

(1) There will be an age effect.
(2) There will be an interface effect.

(3) There will be a task-type complexity effect.
(4) There will be interactions among 3D VR game task performance of task complexity, age, interface, or wayfinding strategy.

2. Method

A 2 × 2 × 2 mixed-design ANOVA was executed, with an age (younger adult/older adult), interface (arrow/intuitive), and task complexity (easy; symmetrical/difficult; bio-symmetrical) experimental design. The first three factors were between-subject designs while the latter was a within-subject design.

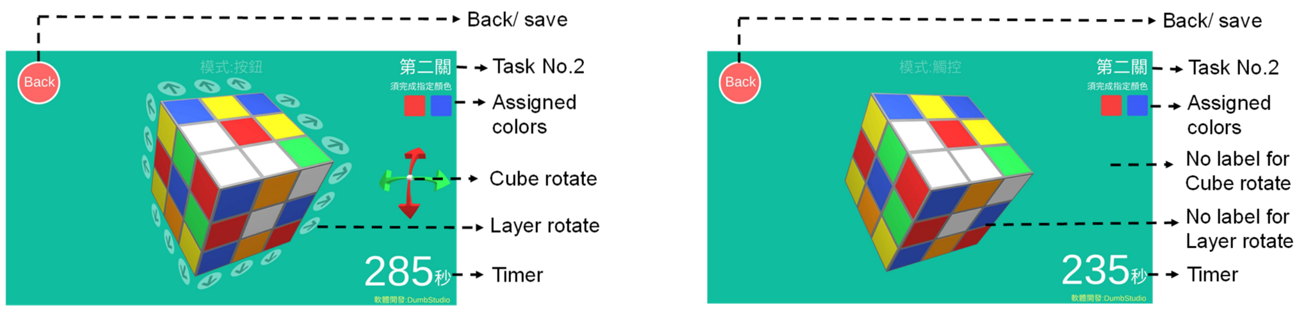
2.1. Participants

All participants were randomly assigned to one of the between-subject factors (sex and control device). For the VR (virtual reality) 3D-simulated Rubik's Cube game experiment (N = 96), younger adult (n = 48) and older adult (n = 48) groups were both evenly recruited. The younger adult group comprised university students from the National Taipei University of Education, Taiwan, and their ages ranged between 18 and 22 (mean = 20.13, SD = 1.4). All the older adult participants were retirees, invited from the Chun Kun apartment complex, Taipei, Taiwan, and were evaluated for participation based on the criterion that they reported daily use of a smart pad. The older adult group ages ranged from 60 to 85 years (mean = 66.9, SD = 5.6). All participants were paid approximately USD 7 per hour for their participation.

2.2. Stimulus and Materials

2.2.1. Interface Design

As Figure 2 shows, two types of interface design for the VR 3D-simulated Rubik's Cube game were proposed, namely arrow and intuitive. The same layout design was used for the two interfaces. The only differences were the rotating arrow labels for the arrowed interface which disappeared for the intuitive interface (Figure 2). In the top-left corner, a red icon labeled "Back" was to return to the beginning page and for data saving. On the right side of the interface, task number, assigned rotating icon, and timer were displayed.



(**a**) (**b**)

Figure 2. The VR 3D Rubik's Cube and the standard model. (**a**) Arrow interface design. (**b**) Intuitive interface design.

(a) Arrow interface design: On the arrowed interface (Figure 2a), the user could touch the arrow or slide on the arrow using a finger to activate the intended rotating movements. There were 44 participants randomly assigned to this interface mode, with 21 younger adults and 23 older adults in the age-split participant group.
(b) Institutive interface design: In the intuitive design (Figure 2b), no direction arrow was labeled, and the users could slide the model intuitively according to their spatial perception. There were 52 participants randomly assigned to this interface mode, with 27 younger adults and 25 older adults in the age-split participant group.

2.2.2. Task Complexity

There were two task complexity levels, easy and difficult. The tasks were to rotate the cubic layers to reallocate the designated cubic face with the same color stickers. To ensure the consistency of the test difficulty, the same pre-set pattern was set for all the Rubik's Cube models (Figure 3). Four Rubik's Cube task icons were shown on the beginning page (Figure 3a); the user could tap on the icon to activate the requested task. The four tasks were free practice (Figure 3b), pre-test (Figure 3c,d), task 1: easy level (Figure 3e), and task 2: difficult level (Figure 3f). The free test and pre-test tasks were set for the practice stage, and tasks 1 and 2 were for the formal experiment.

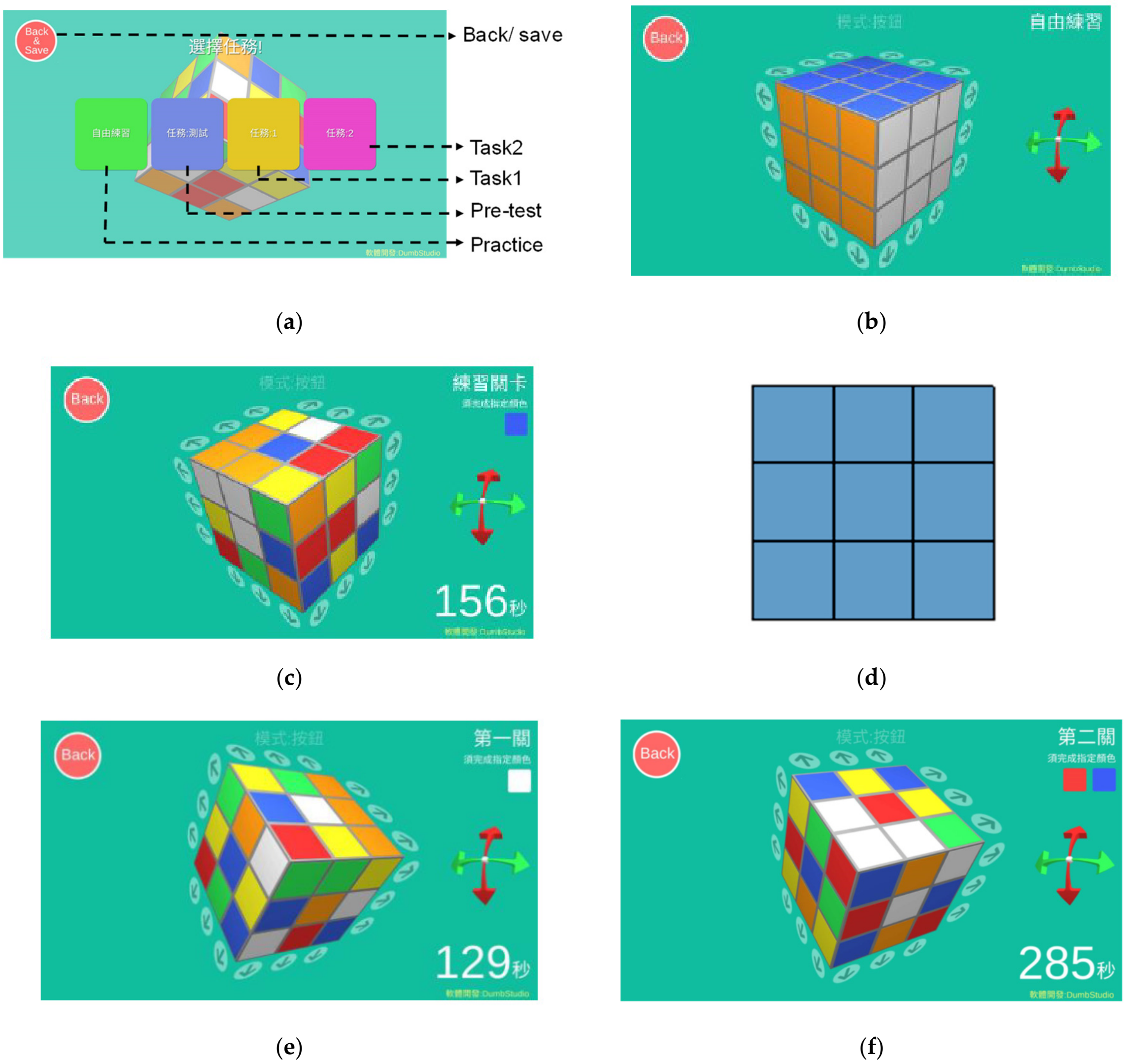


Figure 3. The task designs of the Rubik's Cube game. (**a**) The begin page of the game app. (**b**) The free practice task. (**c**) Pre-test task. (**d**) Assigned blue color for the pre-test. (**e**) Task 1—easy level (single symmetrical). (**f**) Task 2—difficult level (bio-symmetrical).

(a) Easy level, a single symmetrical Task 1 (Figure 3e): In the easy task, the white face was assigned; among the six colored planes (white, red, orange, yellow, green, blue), only the white plane was targeted as the required recovery task. The participants were requested to recover the white plane pattern within 3 min. The uncompleted plane was scored by percentage.

(b) Difficult level, a bio-symmetrical Task 2: Among the six colored faces, two red and blue neighbor faces were targeted as the required recovery task. The participants were requested to recover the colored patterns within 5 min. The uncompleted planes were scored by percentage.

2.2.3. Wayfinding Strategy

Based on the tool developed by Kato and Takeuchi (2003), the SDQ-S/Sense of Direction Questionnaire was applied to determine whether the participants were affected by the wayfinding strategy. There were 20 questions in the questionnaire. The participants were asked to estimate their sense of direction. A 5-point Likert scale (1: strongly disagree and 5: strongly agree) was adopted for measuring the levels.

Factor analysis was conducted, and an initial factor analysis of the scale (principal components, varimax rotation, with four factors specified and renamed) was conducted. After excluding the questions with a factor power of less than 0.4, four factors with 19 questions remained; 66.4% of the total variance was explained, the KMO value was 0.82, and the Bartlett test indicated significance (<0.001).

The resulting factor loadings are shown in Table 1, and four factors were extracted and named. Nine items were found to load most heavily on the first factor; these items represented the same factor of the memory for usual spatial behavior. Four items loaded most heavily on the second factor; these items were named the cognitive map survey. Three items loaded most heavily on the third factor; these items were renamed the familiarity survey. Three items loaded most heavily on the fourth factor; these items represented the awareness of the orientation survey. As the analysis of the correlation among the four factors reached significant levels, the four factors were identified as relatively independent.

Table 1. Full items of SDQ-S form and factor loadings (varimax rotated) for 19 items in this study (N = 96).

New Order	Original Order	Factor Definition and ITEMS	Component		Variance Explained of %
		New Factor 1: memory for usual spatial behavior/ Original Factor: memory for usual spatial behavior			
1	16	I become totally confused as to the correct sequence of the return way as a consequence of a number of left-right turns in the route.		0.880	
2	15	I often (or easily) forget which direction I turned.		0.858	
3	14	I have a lot of difficulties reaching an unknown place even after looking at a map.		0.820	30.94%
4	17	I can't verify landmarks in a turn of the route.		0.811	
5	9	I have a poor memory for landmarks.		0.757	
6	13	I often can't find the way even if given detailed verbal information on the route.		0.746	
7	12	I can't remember the different aspects of scenery.		0.711	
8	10	I cannot remember landmarks found in the area where I have often been.		0.711	
9	18	It is difficult for me to find the destination in the residential area of the same type of house.		0.680	
		New Factor 2: cognitive map/ Original Factor: awareness of orientation			
10	7	I can visualize the route as a map-like image.	*	0.854	
11	6	I can tell where I am on a map.	*	0.748	13.38%
12	1	I can make correct choices as to cardinal directions in an unfamiliar place.	*	0.692	
13	19	I can tell the difference between streets which are very similar to each other.	*	0.634	
		New Factor 3: familiarity/ Original Factor: memory for usual spatial behavior			
14	2	I have become confused as to cardinal directions when I was in an unfamiliar place.		0.847	
15	8	I feel anxious about my walking direction in an unfamiliar area.		0.662	11.23%
16	4	When I get route information, I can make use of "left or right" information, but I can't use cardinal directions.		0.544	
		New Factor 4: awareness of orientation/ Original Factor: awareness of orientation			
17	5	I can't make out which direction my room in a hotel faces.		0.815	
18	11	I can't use landmarks for wayfinding.		0.632	10.90%
19	3	I have difficulties identifying the moving direction of the train with regard to the cardinal direction.		0.583	
-	20	I am totally dependent on others whenever I move in a group.		-	-
		Total Variance Explained			**66.44%**

Extraction method: principal component analysis. * is a reverse-scored question.

2.3. Procedure

After 6 months of development, iterative testing, and programming team work on the interface design by the research team, the 3D VR-simulated Rubik's Cube game for smart pads based on Unity software was used to construct an interactive VR interface. All of the navigational settings were run on a 10″ smart pad (Asus Zen-pad; type: P023/CPU: Intel® Atom™ x3-C3200, 64 bit). Note that the display dimension of the simulated game was adjusted to the full-screen mode (21.7 × 13.8 cm) to have the best display effect.

The experiment procedure:

1. Practice stage: After the experiment and task instructions were provided to participants, they could do the free practice task with no time limitation. At this stage, the user could rotate the layer to practice becoming familiar with the interface. Note that all the participants were situated with the same smart pad interactive condition, 55–65 cm face distance, and 65 tilted angle (Figure 4).
2. Pre-test task stage: After users felt ready for the test, they were asked to go to the second stage, the pre-test task. The cube face with the same blue solid color stickers with a 3 min time limit was set as the VR game task (Figure 3c,d).
3. Task 1 stage (easy level): After the pre-test, a 5 min break was given for rest. Once the user was confirmed to be ready for the next stage, a formal experiment stage, task 1, began (Figure 3e). The percentage of the task completion of the VR game task was processed and recorded as the experimental data for analysis.
4. Task 2 stage (difficult level task): After the task 1 stage, an 8 min break was given for rest. Once the user was confirmed to be ready for the next stage, task 2 began (Figure 3f). The percentage of the task completion of the VR game task was processed and recorded as the experimental data for analysis.
5. Questionnaire stage: After the experimental tasks, the participants were required to fill out the self-report questionnaire on their sense of wayfinding strategy. The full experiment lasted approximately 1 h for each participant.

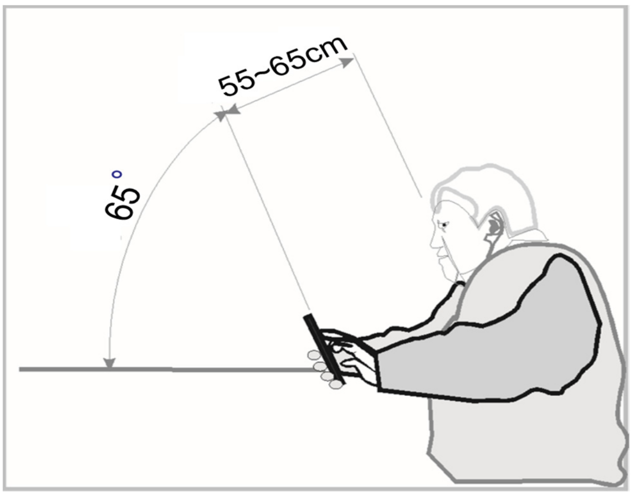


Figure 4. An older adult participant and the display.

2.4. Data Analysis

ANOVA was used to analyze the percentage with the time limit of VR game task performance. The collected data were analyzed using 2 × 2 × 2 mixed-design ANOVA, where age and interface were the between-subject factors, and the two task complexities were the within-subject factors. We then performed post hoc paired comparisons to identify the simple interactive effects among the factors. Regression with enter-method was conducted to further analyze the theoretical model and causal relationship among the variables. Each assigned task was recorded automatically when the task was completed. With neither correct route nor direction to be followed, the statistics of wrong turns and hesitation frequency were confounded. Therefore, neither wrong turns nor hesitation frequencies were analyzed in the present study.

3. Results

3.1. Overall Results

Table 2 presents the means and standard deviations of navigation time by split data of age, interface, and task complexity. The main effect of percentage for the task complexity, easy level, was significantly better than for the difficult task ($F_{(1, 92)} = 5.49$, $p < 0.05$). The main effects of between-subject factors, age and interface, were also noted to be significant. Data showed that arrow design was significantly better than intuitive design ($F_{(1, 92)} = 5.52$, $p < 0.05$). The main effect of age was also found to be significant ($F_{(1, 92)} = 16.50$, $p < 0.001$), as the younger adult group had better task performance than the older adult group. The data revealed a two-way interactive effect, but the three-way interactive effect was not significant in the data collected. A two-way interactive effect was found between age and task complexity ($F_{(1, 92)} = 8.78$, $p < 0.001$) (Figure 5).

Table 2. Means and standard errors of VR game task performance.

				Task Type				
Age	**Interface Design**	***N* = 96**		**Easy; Mean (Sd.)**		**Difficult; Mean (Sd.)**		**Ave.**
Younger adults	Arrow	21		62.5	(19.1)	60.1	(13.9)	61.3
	intuitive	27		52.6	(15.3)	57.2	(12.5)	54.9
			Ave.	57.6		58.7		58.1
Older adults	Arrow	23		56.1	(13.4)	46.5	(6.7)	51.3
	intuitive	25		52.5	(14.8)	43.2	(8.1)	47.9
			Ave.	54.3		44.9		49.6
Unit:%								

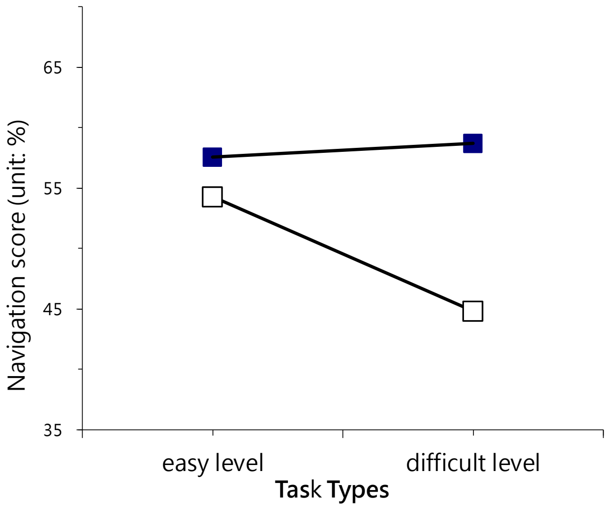


Figure 5. Effects of age (■ younger adult group, □ older adult group) and task complexity on VR Rubik's Cube game task performance.

A significant effect was seen in the older adult participants between task complexities. Thus, the older adults scored their best VR game task performance on the easy level and worst on the difficult task level. Nevertheless, no significant difference was found in the VR game task performance of the younger adult participants for both task conditions. These data suggest that the type of task level significantly affected the older adults but did not affect the younger adults' VR game task performance.

3.2. Regression

To further identify a theoretical model and causal relationship among the variables, regression using the enter method was computed. Results indicated that task complexity, interface, and two wayfinding strategies significantly affected the participants' VR game task performance. The theoretical model could explain 91.5% (R square = 0.915) of the variance in navigational performance, $F_{(7, 85)} = 4.86$, $p < 0.001$ (Table 3. As indicated by the individual variable effect, task complexity ($T_{(7, 85)} = 3.16$, $p < 0.001$), interface ($T_{(7, 85)} = 2.01$, $p < 0.05$), wayfinding strategy of memory for usual spatial behavior, ($T_{(7, 85)} = -4.06$, $p < 0.05$), and familiarity ($T_{(7, 85)} = 2.32$, $p < 0.05$) all reached statistically significant levels. That is, interface and wayfinding strategy did significantly affect the participants' VR game task performance. However, the wayfinding strategies could also affect VR game task performance positively or negatively: the lower the score on memory of the usual spatial behavior wayfinding strategy, the better the VR game task performance, while the result was the opposite for familiarity.

Table 3. Coefficients (a).

	Standardized Coefficients		
	Beta	***t***	
Task2 (difficult level/bio symmetrical)	0.513	3.16	**
Age	0.063	1.56	
Interface	0.070	2.01	*
Wayfinding strategy1/memory for usual spatial behavior	−0.089	−4.06	*
Wayfinding strategy2/cognitive map	0.033	1.60	
Wayfinding strategy3/familiarity	0.046	2.32	*
WayfindingsStrategy4/awareness of orientation	0.003	0.116	
R square	**0.915**		
F	**4.86**		
df	**7, 85**		
p	**0.0001**		

Dependent variable: task1 (easy level); * $p < 0.05$, ** $p < 0.01$.

4. Discussion

4.1. Main Effects

Experimental results showed that VR game task performance for age, interface, and task complexity were all found to be significant. Regarding the age effect, the younger adult group resulted in better task performance than the older adult group (younger adult = 58.1%; older adult = 49.6%). Therefore, the first hypothesis, that there would be an age effect, was supported by the research results. One possible reason is similar to the statement regarding a decline with age [21]. Previous studies have argued that the related brain structures in the medial temporal lobe declining due to the age effect may impact the capacity for encoding cognitive maps [22]. The age effect also appears in sensory perceptive impairment, and special learning may be impaired when HPC and sensory deterioration happen [23,24].

As for the interface factor, there was a significant effect found (arrow = 56.3%; intuitive = 51.4%). Thus, the second hypothesis, that there would be an interface effect, was supported by the research results. The score on the arrow interface was significantly better than that on the intuitive interface. It was noted in the VR game task experiment. A possible reason is that the Rubik's Cube game with a third axis rotation is considered to have a more difficult spatial capacity that is beyond ordinary human spatial comprehension. A previous study argued that the perception of reality and users familiar with VR environments might obscure comparisons of VR performance [16,25]. Although two interfaces were designed to have evenly smooth and sensitive responding movements to the user's finger touch or slide, participants seemed to have more certainty and better interaction with the arrow interface. On the arrow interface, rotations can only be triggered by the corresponding arrow icon, resulting in better task performance than the intuitive interface that has no limitations on the position. Note that there are six faces on a Rubik's Cube; thus, the spatial orientation of the intended plane of rotation is crucial in this toy game. The arrow interface with strict rotating movements resulted in better performance than the intuitive interface with free spatial interaction.

In terms of task complexity, a significant effect was noted (easy task = 55.9%; difficult task = 51.8%), where the easy task resulted in a better performance than the difficult task as the experiment design. Previous studies found that one of the reasons Rubik's Cube became popular is the challenges of the complex levels of spatial orientation and brain processing [26]. As a previous study also indicated [27], task complexity may interact with other VR effects such as individual differences or interface. It was anticipated in the experiment design to have different task levels for the users, as will be discussed in the next section. The third hypothesis, that there would be a task complexity effect, was supported by the research results. An interactive effect on task complexity and age was also noted, and will be discussed in the next section.

4.2. Age Difference and Task Complexity

The two-way interactive effect between age and task complexity was found to be significant. The fourth hypothesis that there will be interactions among 3D VR game task performance of task complexity, age, interface, or wayfinding strategy was supported by the study results. Split data showed no significant difference in either task type for the adult group (easy task = 57.6%; difficult task = 58.7%). For the older adult group, in contrast, a significant effect was found between the easy task and difficult task (easy task = 54.3%; difficult task = 44.9%) VR game task performance.

These results are consistent with previous studies which claimed that individual difference and task complexity effects may be interactively correlated. One of the main reasons is, as a previous study has argued, that individual differences appear only when the task difficulty level reached the threshold of the difference of the special capacity [24,28]. Despite the physical decline caused by the age effect, the second correlative possible reason is a learning effect [29,30], since the young group possessed a better interface and VR game task performance than the older group, which might have eliminated the effect task complexity in the younger adult group.

4.3. Theoretical Model

As the regression analysis further revealed, task complexity, interface, and wayfinding strategy (memory of usual spatial behavior and familiarity) all reached statistically significant levels. It was also noted that the higher the score on the familiarity wayfinding strategy, the better the task performance, while the result was opposite for memory of the usual spatial behavior wayfinding strategy. A possible explanation is that the age effect may be impaired by the other effect on the complex task conditions [13], and thus participants may not have benefited from the interface and wayfinding strategy. As noted in the previous study argument, wayfinding strategies may not be independent [31], which may have been affected by the task complexity and age effect in this research. The study is not only consistent with the previous study [20] on the argument of the VR task performance and wayfinding self-report analysis; it also extends the exploration of the correlation among the age and interface effects. The results suggest that a control device specifically developed to overcome the familiarity effect may provide a better operating experience for older adults.

Note that this experiment did not include the case of using the two interfaces simultaneously. A previous study argued that coexisting systems would obscure the comparison of the interfaces [32]. Thus, at present, the participants paid attention to only one of the two interfaces randomly offered. A future enhancement of the present study would be to include other kinds of measuring metrics (measurement of user behavior or neural signal) [30] and gender or anxiety effect [33,34] to further uncover the interactions among

VE characteristics, task complexity, individual difference, and the subject self-report of the VR experience.

5. Conclusions

The summary of the study results:

(1) The experimental results and statistical analysis indicate that task difficulty did significantly affect the 3D VR Rubik's Cube game task performance.
(2) Users had significantly better performance on the easy than on the difficult task type. The arrow interface was significantly more effective than the intuitive interface for the smart pad.
(3) The interactions between age and task complexity indicate that the task effect only affected the older but not the younger adult participants.
(4) The theoretical model regression analysis among task complexity, interface, and wayfinding strategy did affect the participants' VR game task performance, and the effect was proved to be significant. It was revealed that the study results indicated that users may be positively or negatively affected by the wayfinding strategy.

In conclusion, it is important to note that an excellent VR technology that does not have a good interface design that meets the user's needs and task conditions, will inevitably affect the user's operational performance and operational satisfaction. In other words, an excellent VR technology is complemented by the interface design developed with the user-centered concept. The results of this study can be used to evaluate the interface designs of VR games, taking into consideration age difference, task complexity, experiential self-report on 3D VR games, and including VR rotation navigational systems.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of ROC, TAIWAN, and approved by the Research Ethics Committee National Taiwan University.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Project report of National Science Council MOST 103-2420-H-152 -005 -MY2.

Conflicts of Interest: The author declare no conflict of interest.

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