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Usability of Interactive 3-Dimension Virtual Reality Game on Dual Cognitive Task for Stroke Rehabilitation

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ABSTRACT

Usability can be considered to be extent to which a product can be used by specified participants to achieve specified goals in a specified context of use with effectiveness, efficiency and satisfaction. Virtual reality game can be designed for many types of participants. Running game usability testing sessions with stroke patient is the best way to ensure that the final product delivers the best possible virtual reality game experience During rehabilitation process, six stroke patients were selected based on inclusion and exclusion criteria. The data gathered were then evaluated accordingly to the stroke patient walking speed, number of steps, balance test, time efficiency, game score and usability testing from stroke patients, therapist and game experts. This paper reveals findings from a usability assessment conducted on the serious game using the Interactive Cognitive Motor Training (ICMT) technique, which was developed for stroke patient on dual cognitive task rehabilitation. The result proved that the virtual reality game can be used as a rehabilitation tools for stroke patients.

Key words : serious game; stroke rehabilitation; virtual reality; dual cognitive task.

1. INTRODUCTION

The interactive three-dimensional (3D) virtual reality game environment for rehabilitation requires minimal assistance from therapist to facilitate patients to recover their body function especially in dual cognitive task problem [1], [2] are many considerations in creating a virtual reality 3D game for the dual cognitive task stroke rehabilitation require such as game elements, game theory and game genre. Moreover,in order to design a virtual reality game, a high attention must be given on the ability of the stroke patient to use the virtual reality equipment which is not burden them[3], [4] low cost of virtual reality equipment [5], [6].Previous paper, we have discuss the framework and the development of virtual reality game on dual cognitive task for stroke patient [3]. Furthermore, this paper will evaluate the usability of virtual reality game using Interactive Cognitive Motor Training (ICMT) for the rehabilitation of a dual cognitive task for a person with a stroke. The usability testing will conducted to stroke patient, therapist and also the game expert to measure this game is suitable for stroke patient dual cognitive task rehabilitation.

2. REHABILITATION PROSES

The virtual reality game consists of three levels, Level 1, Level 2 and Level 3. In this game, the participant was wearing the oculus of virtual reality, walking along 6 meters on a flat ground and counting the number. This rehabilitation process took about 45 to 60 minutes.

2.1 Selecting participant

From articles by[7], [8], the suitable number of participant for usability testing is five participants. However, the number of participants will be based on the following previous studies:

a. 4 persons with stroke (3 men) received 30-minute training sessions using the game device to determine the efficacy and reactions of stroke patients to a game-based rehabilitation modality for more affected upper limbs[9]
b. Six persons with chronic stroke (> 6 months) underwent 2 sessions / week each. The 2 participants underwent conventional gait training, while 4 participants underwent gait training using the Walk-Even [10]
c. A feasibility study on integrative motor and cognitive therapy for elderly patients was conducted for 5 participants (1 female and 4 male) between the ages of 62 and 81 years [11].

Therefore, an estimated participant sample for this study is six based on the largest number of participants in the previous study above. In addition, all participants should meet the following criteria for inclusion and exclusion in table 1.

Table 1: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Inclusion criteria for participants with stroke: ▪ Able to walk 6m with and without the use of an assistive device ▪ Aged between 40 to 60 years old at the time of recruitment ▪ No heart disease or uncontrolled hypertension. ▪ Have the ability to understand instructions in English as recommended by the attending physician ▪ Have the ability to communicate verbally in English ▪ Consented for the study	Exclusion criteria for participants with stroke: ▪ Musculoskeletal and neurological conditions that influence walking other than stroke. ▪ Visual disability ▪ Inability to tolerate the oculus virtual reality HTC Vive head mounted gear

2.2 Room setup

Figure 1 below shows the room for virtual reality that will be set up before the game is played by the participant. Hardware uses include the laptop, HTC vive oculus, and wall sensor detection.

Figure 1: virtual reality room

2.3 Experiment

Therapist checked patient Vital sign assessment for blood pressure and heart rate to determine patient health. Participants will be briefed on the game, how the game will be conducted and what they need to do to complete the dual cognitive rehabilitation task. If agreed, they should sign the consent form and photographic form.The therapist measured the height and weight of the participant to set in the APDM mobility lab application that shown in Figure 2.

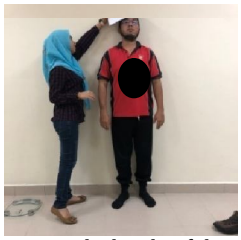

Figure 2: Measure the height of the participant

If the participant has played that provided in English, the patient must answer the questionnaire about previous game experience and knowledge about virtual reality game. The result was shown below.Before the experiment they were instructed to perform several tasks that are straight walking for 6 meters and static standing for 30 seconds. As they perform these tasks, the therapist put the strap on the ankles and waist to analyse the movement as shown in Figure 3 and Figure 4 below. This device will not harm them. This is for calculating patient stroke walking speed, number of steps and total sway. This will be done before and after the game of virtual reality has been played. The result of all participants' total sway, step velocity and also cadence will be discussed below.

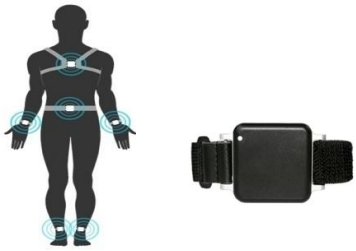

Figure 3: APDM Mobility Lab

Figure 4: Stroke patient is wearing the APDM mobility lab

This game has three game levels that the participant should say number back from 10 to 1, say number multiple from 2 to number 20 and number subtraction -7 from 100 while wearing the HTC Vive shown in Figure 5 below.the development of virtual reality game has been discuss in previous paper[4].

Figure 5: HTC Vive

3. OUTCOME MEASUREMENT

The outcome of the assessment is summarized based on the distinction between walking velocity pre- and post evaluations, amount of steps, balance test, time to finish the game, game score, post-virtual reality exposure questionnaire. The descriptions of the assessment criteria can be found in Table 2. In order to assess the usability of virtual reality game on dual cognitive assignment for stroke rehabilitation using interactive cognitive motor training (ICMT) method and participants in the theory of Prisoner Dilemma, participants, therapist and game experts must answer the usability questionnaire.

Table 2: Evaluation criteria

Evaluation criteria	Description	Parameter
Walking speed	Calculate participant stride velocity before and after playing virtual reality game using APDM mobility lab	How many meters per second
Number of steps	Calculate participant cadence before and after playing virtual reality game using APDM mobility lab	How many steps per minutes
Balance test	Calculate participant total sway before and after playing virtual reality game using APDM mobility lab	How many sways per unit of time
Time efficiency	To measure the time taken to complete every level of game. The less the execution time, the better is the time efficiency.	Execution time
Game score	For every level, the game score is given by therapist with correct number of counting, and number of errors	Score over 10
Usability testing	To evaluate the usability of virtual reality game for rehabilitation	Usability questionnaire

Moreover, during the rehabilitation phase, the participants score, the therapist calculated a number of counting errors and time to complete the dual cognitive task. The overall outcome is shown below in Table 3.

Table 3: Participants' score, number of error and time to complete the dual cognitive task

Subject ID	Level 1			Level 2			Level 3		
	Score	Number of errors	Time to complete /s	Score	Number of errors	Time to complete /s	Score	Number of errors	Time to complete/ s
VR01	10	0	11.1	10	0	8.9	5	1	54.5
VR02	10	0	12.4	9	1	12.4	2	0	13.9
VR03	10	0	13.6	10	0	10.7	2	0	28.0
VR04	10	0	9.4	9	1	9.0	5	0	24.2
VR05	10	0	10.0	10	0	18.0	4	1	32.0
VR06	10	0	8.6	10	0	19.0	4	0	11.5
Mean			10.9			13.0			27.4

Figure 6 reflects the level 1, level 2 and level 3 game score from the stroke patient's six participants. Furthermore, for Level 1, all participants received a complete score. Four participants received 10 score for Level 2, and another 2 participants received 9 scores. Additionally, the high-score participant has only 5 for Level 3, which is the difficult stage, and others have 4 and 2.

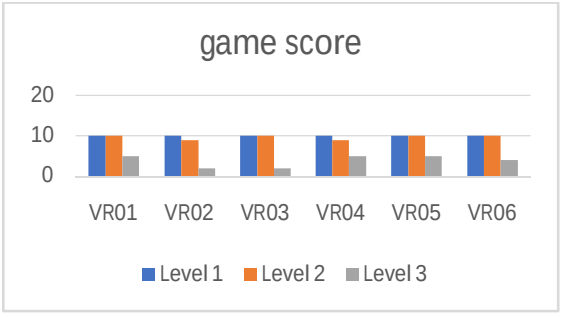

Figure 6: Participants' score

Figure 7 represents the amount of errors during counting. For level 1, no mistake can be counted by all participants. Additionally, there is one counting mistake for Level 2, VR02 and VR04. Furthermore,

the VR01, VR05, and VR06 confronted one counting mistake for Level 3, which is the difficult stage.

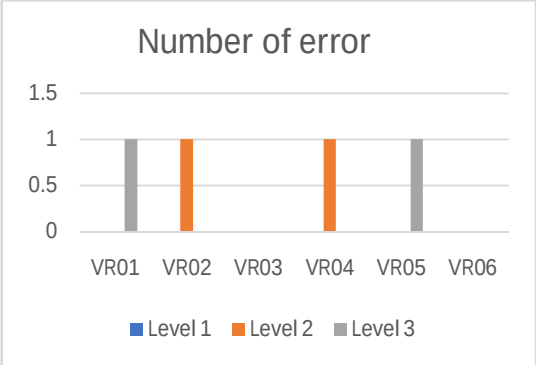

Figure 7: Number of errors

Figure 8represents the time from six participants of the stroke patient to complete the dual cognitive task within 6 m walking distance for Level 1, Level 2 and Level 3. Level 1's mean completion time is 10.9 seconds. The mean completion time for Level 1 is 10.9 second. In addition, the completion time for level 2 is 13 seconds, and the completion time for level 3 is 27.4 seconds longer than other levels. It took the time using a stopwatch.

Figure 8: Time to complete every level of game

Total Sway, step velocity, and cadence were calculated using the APDM mobility lab during the walking phase. Six participants ' results were shown in Table 4 below.

Table 4: Total sway, stride velocity and cadence

Participant ID	Total Sway area (m^2s^5) Pre-test	Total Sway area (m^2s^5) Post test	Stride velocity St (m/s) Pre-test	Stride velocity St (m/s) Post test	Cadence (steps/min) Pre-test	Cadence (steps/min) Post test
VR01	0.00198	0.0133	0.825	1.01	84.4	98.6
VR02	0.0145	0.0198	0.945	0.974	91.6	92.1
VR03	0.0025	0.00169	1.14	1.02	98.5	91.8
VR04	0.0142	0.000705	1.12	1.17	96.7	98.6
VR05	0.00385	0.00165	0.64	0.649	91.4	91.3
VR06	0.00469	0.00439	0.85	0.981	95.9	103

Based on Table 4, the Wilcoxon test was conducted for each stroke patient for pre-test and post-test. Figure 9 shown the total sway area for six participants. Four of them decrease total sway area are after played the virtual reality game. However, for VR01 and VR02, their total sway area increases by 36% and 20%. The p-value for total sway is. 0.0028 which is smaller than 0.005 ($p < 0.005$). Based on these values, the difference between post-test and pre-test is significant. That means there was a significant improvement between pre-test and post-test for the stroke patient after using the virtual reality game.

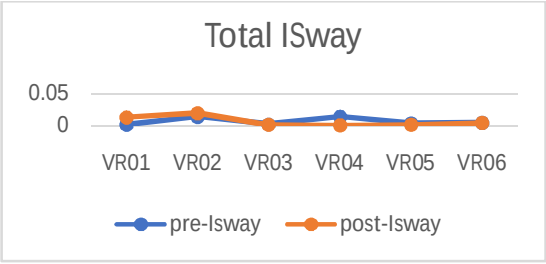

Figure 9: pre-test and post-test Total ISway

Furthermore, in Figure 10, five participants increase the stride velocity after played the virtual reality game. However, only one of them which is VR03 is decreased 12% stride velocity compare to pre-test. p-value for stride velocity is 0.0021 which is smaller than 0.005 ($p < 0.005$). Based on these values, the difference between post-test and pre-test is significant. That means there was a significant improvement between pre-test and post-test for the stroke patient after using the virtual reality game.

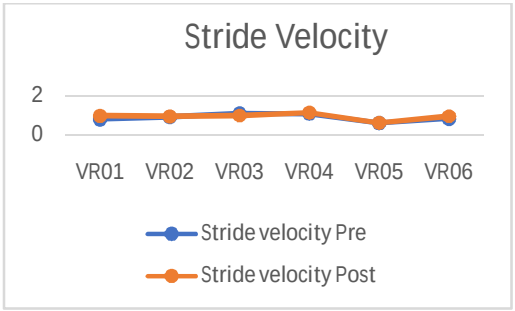

Figure 10: pre-test and post-test Stride velocity

In addition, Figure 11 is for cadence, five participants got improvement which increases their cadence step but only VR05 decrease about 1% after playing the game. P-value for cadence is 0.0027 which is smaller than 0.005 ($p < 0.005$). Based on these values, the difference between post-test and pre-test is significant. That means there was a significant improvement between pre-test and post-test for the stroke patient after using the virtual reality game.

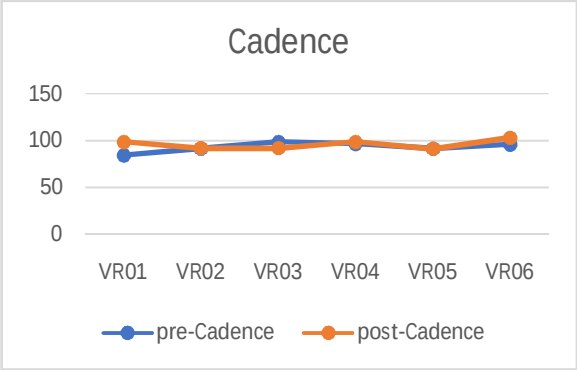

Figure 11: pre-test and post-test Cadence

4. USABILITY OF VIRTUAL REALITY GAME

4.1 Usability testing

Usability testing can be answered by participants, therapist, and game expert. The participants would answer this usability test after they play the virtual reality game. Furthermore, the therapist and game expert were answering the usability test of the virtual reality game in order to be used for the stroke patient as their rehabilitation tool.

A. Usability test: therapist

For the therapist, the usability test is more to virtual reality device, whether it is suitable for a stroke patient in order to do the dual cognitive task rehabilitation. It has been tested for five therapists at Specialist Centre UiTM Sg. Buloh which one male and four female around age 20 to 40. Table 5 shows the details of the personal information of the therapist.

Table 5: Personal information of therapist

Therapist ID		Numbers	Percentages %
Gender	Male	1	16.7
	Female	4	83.3
Age	20-30	2	40
	31-40	3	60
	41-50	0	0
	51-60	0	0

From Table 6, the finding shows that the therapist usability test on virtual reality game with 58% on Very Agree and Agree score and the average mean is 3.40.

Table 6: Usability testing for therapist

Participant/Description	1 Strongly Disagree (%)	2 Disagree (%)	3 Normal (%)	4 Agree (%)	5 Strongly Agree (%)	Mean
I think I would like to use the stroke rehabilitation device often	0 0	0 0	0 0	5 100	0 0	4.00
I think the stroke rehabilitation device is difficult to use	0 0	3 60	1 20	1 20	0 0	2.60
I think the stroke rehabilitation device is easy to use	0 0	0 0	1 20	3 60	1 20	4.00
I required technical assistance to use the stroke rehabilitation device	0 0	0 0	2 40	2 40	1 20	3.80
I think the functionalities of the stroke rehabilitation device are well integrated	0 0	0 0	1 20	4 80	0 0	3.80
I think the functionality of the stroke rehabilitation device are not organized	4 80	0 0	1 20	0 0	0 0	1.40
I think most of users will be learn to use the device quickly	0 0	0 0	1 20	1 20	3 60	4.40
I think most of the users will have difficulties learning to use the stroke rehabilitation device	2 40	1 20	0 0	2 40	0 0	2.40
I am confident when using the stroke rehabilitation device	0 0	0 0	2 40	2 40	1 20	3.80
I may need to learn more background information before I am able to use the stroke rehabilitation device	0 0	0 0	2 40	2 40	1 20	3.80
Total amount of percentage	12	8	22	44	14	3.40

Figure 12 below shown all the therapist give a positive vote for virtual reality equipment with 40% strongly agree, 40% agree that virtual reality equipment was easy to used.

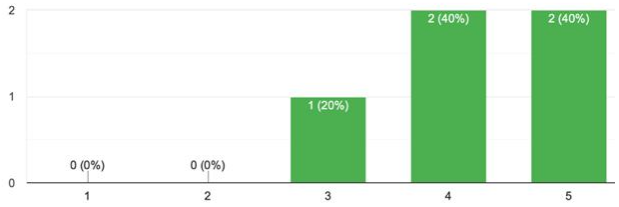

Figure 12: Virtual reality easy to use

Figure 13 below shown four therapists 80% agreed that virtual reality functionality was well integrated

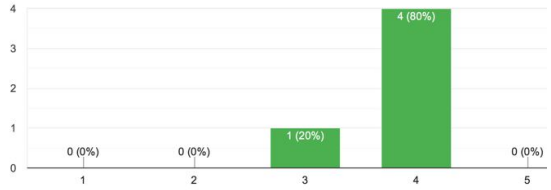

Figure 13: Virtual reality functionality are well integrate

The therapists need technical assistance in order to set up the virtual reality equipment before it can be used to stroke patients as shown in Figure 14 most of them vote for agreed and strongly agreed.

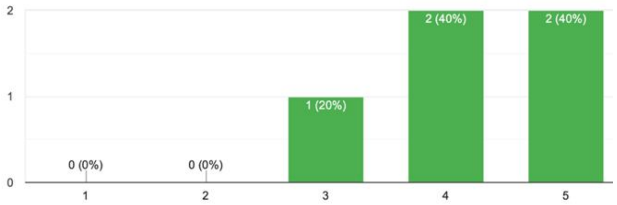

Figure 14: Required technical assistance to use virtual reality

From the result in Figure 15, all therapist 100% were confident using virtual reality as a rehabilitation tool.

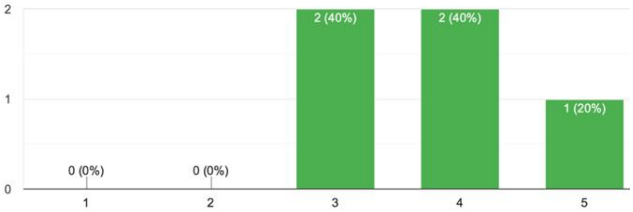

Figure 15: Therapist confident using the virtual reality.

From therapist usability test in Figure 16, they agreed that stroke patient can learn the virtual reality quickly.

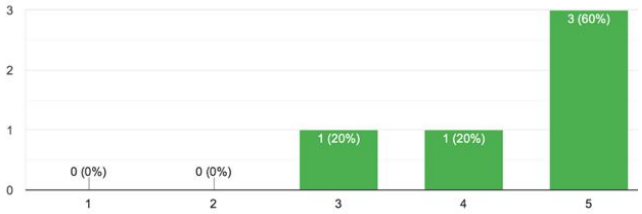

Figure 16: Stroke patient will learn virtual reality quickly

Furthermore, all of them 100% agreed with this virtual reality game using HTC vive headset can be used as a rehabilitation tool for the stroke patient. Virtual reality device was easy to use, not too difficult to handle and they will use this device often. All the functionality of the device is well integrated although they need a technical assistant to set up the virtual reality device. Furthermore, the therapist was confident during virtual reality usability testing and sure stroke patient will quickly learn to use this virtual reality device as their rehabilitation tool. As a conclusion, this virtual reality device can be used as rehabilitation for stroke patient on the dual cognitive task.

B. Usability testing: game expert

In addition, the usability test for the game expert was divided into seven categories which were the visual category, auditory category, interface category, distraction category, enjoyment category, cybersickness category and field of view category. This test was held in order to know all the categories of the virtual reality game was suitable and can be used as rehabilitation tools for stroke patients. It has been tested for five game expert which two male and three female around age 20 to 40. Table 7 shows the detail of the game expert.

Table 7: Personal information of game expert

Therapist ID		Numbers	Percentages %
Gender	Male	1	16.7
	Female	4	83.3
Age	20-30	2	40
	31-40	3	60
	41-50	0	0
	51-60	0	0

Table 8 shows the finding on the game expert usability test on virtual reality game with 73.88 % on Very Agree and Agree score and the average mean is 3.85.

Table 8: Usability testing for game expert

Participant/ Description	1 Strongly Disagree (%)	2 Disagree (%)	3 Normal (%)	4 Agree (%)	5 Strongly Agree (%)	Mean
Category: Visual						
How natural was the virtual environment?	0 0	0 0	0 0	3 60	2 40	4.40
How real was the virtual environment?	0 0	0 0	1 20	1 20	3 60	4.40
Category: Auditory						
The sound effect helped me feel like I was in the environment	0 0	0 0	2 40	1 20	2 40	4.00
Were you able to distinguish between different sound?	0 0	0 0	0 0	0 0	5 100	5.00
Category: Interface						
The interface was easy to use	0 0	0 0	0 0	2 40	3 60	4.60
The interface was felt natural to use	0 0	0 0	0 0	2 40	3 60	4.60
How much disparate did you feel the virtual world was from the real?	0 0	0 0	1 20	3 60	1 20	4.00
When carrying out the task did you think you were concentrated, focused or immersed?	0 0	0 0	1 20	3 60	1 20	4.00
How much did you feel like looking at a real environment?	0 0	0 0	1 20	2 40	2 40	4.20
Category: Distraction						
How much were you distracted by the test environment?	2 40	3 60	0 0	0 0	0 0	1.60
Were you able to remember what environment object was present?	0 0	0 0	0 0	4 80	1 20	4.20
Category: Enjoyment						
How much did you enjoy navigating through the environment?	0 0	0 0	0 0	4 80	1 20	4.20
Category: Cybersickness						
Did you feel sick navigating through the environment?	2 40	3 60	0 0	0 0	0 0	1.60
Category: Field of view (FOV)						
Was the field of view sufficient for navigating through the environment?	0 0	0 0	1 20	2 40	2 40	4.20
Total amount of percentage	6.15	9.20	10.77	41.52	32.36	3.85

From a usability test on game experts, Figure 17 shown 40% of them strongly agreed and 60% more agreed that the virtual reality game has a natural environment.

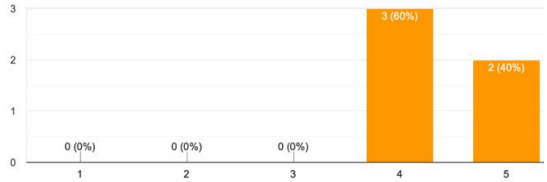

Figure 17: Natural virtual environment

Figure 18 shown 60% of game expert strongly agreed, 20% agreed that virtual reality game looks like a real virtual environment.

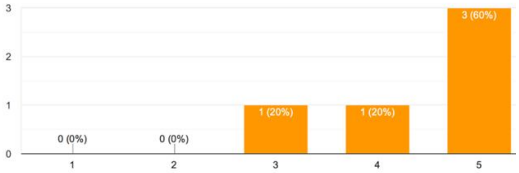

Figure 18: Real virtual environment

As a conclusion, the visual category of the virtual reality game was a natural environment and it looked like a real environment.

Furthermore, on the interface category, 60% of game expert strongly agreed and 40% more agreed that this virtual reality game interface was easy to use and felt very natural based on Figure 19 and Figure 20

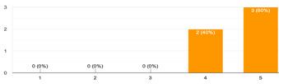

Figure 19: Interface is easy to use

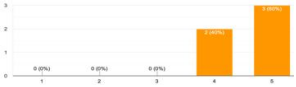

Figure 20: Interface is natural to use

During the dual cognitive task, 40% of the participants strongly agreed and 60% more agreed that they felt the virtual reality game was consistent of visual, auditory and also the haptic simulation during the walking task as shown in Figure 21.

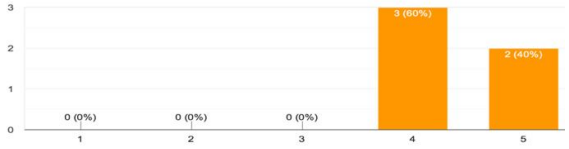

Figure 21: Feeling consistent of visual, auditory and haptic simulation

Furthermore, 20% of the game expert strongly agreed, and 60% agreed that they were felt concentrate, focused and felt immerse into the game based on Figure 22 below.

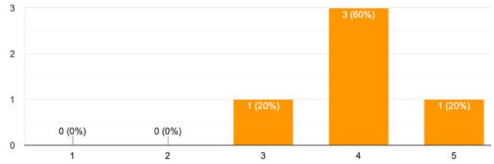

Figure 22 : Feeling concentrate, focus and immerse into the game

The result of the usability test on game experts, 100% of them did not feel any distracted during playing the game based on Figure 23.

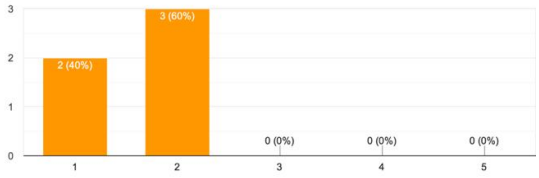

Figure 23: Feeling distracts

In enjoyment category, Figure 24 below shown that game expert was enjoyed navigating through the virtual reality environment with 20% of them strongly agreed and 80% were agreed.

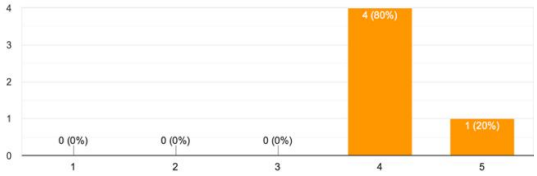

Figure 24: Enjoy navigating through environment

From the result in cybersickness category, Figure 25 below, 40% strongly disagreed and 60% disagreed that they felt sick during navigating through the environment.

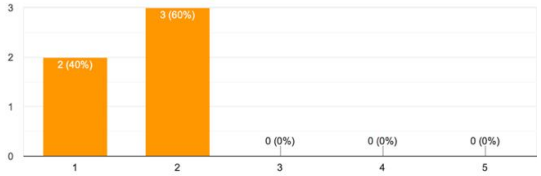

Figure 25: Feeling sick navigating through environment

Besides, game experts agreed that the virtual reality game gave a sufficient field of view that navigated through the environment based on Figure 26 below.

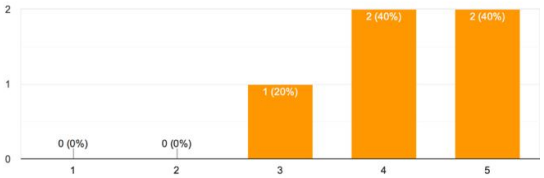

Figure 26: sufficient FOV for navigating through environment

As a conclusion, during played the virtual reality game, game expert enjoyed walking through the environment. They did not felt sick wearing the HTC vive and felt comfortable navigating the environment. Although in this game have interruption with the object and sound from surrounding likes talking people and vehicles, they did not felt distracted and still remembered the object that was present. This game also has sufficient feel of view navigating through the environment. Overall, from the result of game experts, it shows that this 3-dimensional virtual reality game can be used for dual cognitive task rehabilitation.

C. Usability test : Participant

In addition, the usability test for the participant was held in order to ensure that the virtual reality game and its device were suitable for them to do dual cognitive task rehabilitation. It has been tested for six participants the same as pre-assessment before.

In addition, Table 9 shows the finding shows that the participants usability survey on virtual reality game with total 70 % on Strongly Agree and Agree score and the average mean is 3.92.

Table 9: Usability testing for participants

Participant/description	1 Strongly Disagree (%)	2 Disagree (%)	3 Normal (%)	4 Agree (%)	5 Strongly Agree (%)	Mean
I think I would like to use this virtual reality frequently	0 0	0 0	0 0	1 16.67	5 83.3	4.83
I found the virtual reality unnecessary complex	0 0	2 33.33	2 33.33	0 0	2 33.33	3.33
I thought the virtual reality was easy to use	0 0	0 0	1 16.67	1 16.67	4 66.66	4.50
I think that I would need the support of technical person to be able to use this virtual reality	0 0	0 0	0 0	1 16.67	5 83.3	4.83
I found the various function of this virtual reality were well integrated	0 0	0 0	0 0	1 16.67	5 83.3	4.83
I thought there was too much inconsistency in this virtual reality	0 0	2 33.33	1 16.67	1 16.67	2 33.33	1.83
I would imagine the most people would learn to use this virtual reality very quickly	0 0	0 0	0 0	2 33.33	4 66.66	4.67
I found the virtual reality very awkward to use	1 16.67	3 50	2 33.33	0 0	0 0	2.17
I felt very confident using the virtual reality	0 0	0 0	0 0	0 0	5 100	5.00
I needed to learn a lot of things before I could get going with this virtual reality	0 0	1 16.67	3 50	1 16.67	1 16.66	3.33
Total amount of percentage	1.67	13.33	15	13.33	56.67	3.93
Please give your overall rating of user friendliness of this virtual reality technology	Excellent	Best imaginable	Good	Excellent	Good	Excellent

From Figure 27 below, 83.3% of participants strongly agreed and 16.7% agreed that they want to use the virtual reality frequently as their rehabilitation.

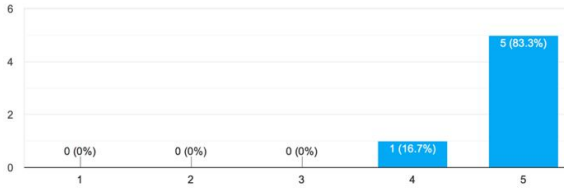

Figure 27: Use virtual reality frequently

Besides, 100% of them agreed that the virtual reality device was easy to use based on Figure 28.

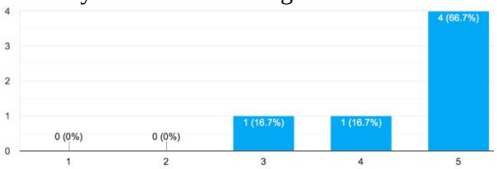

Figure 28: Virtual reality device is easy to use

However, in Figure 29 below, all of the participants need technical support in order to use the virtual reality device.

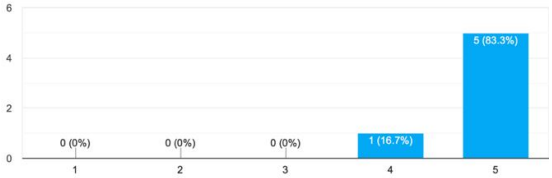

Figure 29: Need technical support before using virtual reality device

Furthermore, five of the participants 83.3% strongly agreed that the virtual reality well integrated that shown in Figure 30 below.

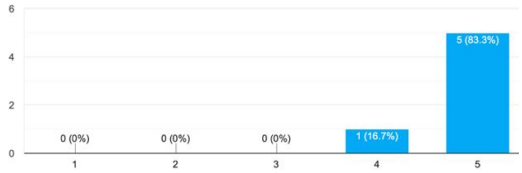

Figure 30: Function of virtual reality are well integrate

Based on Figure 31, all participant not felt awkward during using the virtual reality device.

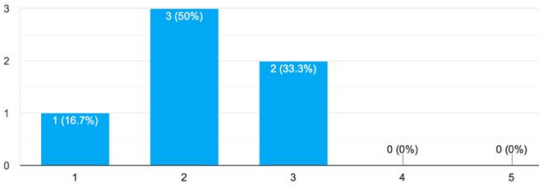

Figure 31: Feeling awkward to use virtual reality device

Figure 32 below shown 100% of six participants felt confident to use the virtual reality device.

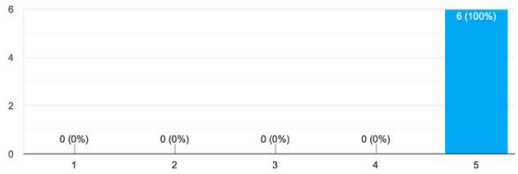

Figure 32: Feeling confident to use virtual reality device

Figure 33 below shown the user-friendliness rating from the stroke patient. 33% vote for good, 50% for excellent and 16.7% more felt the virtual reality is the best imaginable. Therefore, the virtual reality game can be used on dual cognitive task rehabilitation for the stroke patient.

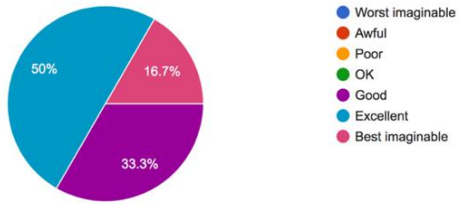

Figure 33: Rating for user friendliness of virtual reality technology

Based on participants, they were confident using virtual reality as their rehabilitation dual cognitive task tool although sometimes they felt awkward because of the first time wearing the HTC vive oculus. From the result of the survey, the virtual reality is easy to use, very integrate into the environment and they want to use this virtual reality frequently. As a beginning, stroke patient needs technical support in order to learn how to handle the virtual reality device. As a conclusion, the virtual reality game can be used for dual cognitive task rehabilitation.

5. CONCLUSION

As a conclusion, the result shows that the positive feedback from therapist, game expert and most important is stroke patient on the virtual reality game. This can be conclude that virtual reality game using interactive cognitive motor training (ICMT) technique that combines walking and counting the numbers is suitable for stroke patients on dual cognitive task. The findings of stroke patient usability test, therapist and also game expert enable the virtual reality game to become a tool for dual cognitive task rehabilitation. The development of 3-dimensional virtual reality game on dual cognitive task for stroke rehabilitation can be used for clinical purposes to help patients with stroke get better.

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