An Innovative Virtual Reality System for Mild Cognitive Impairment: Diagnosis and Evaluation

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***Abstract*—In advanced countries throughout the world, the population of Alzheimer's Disease(AD) patients has been gradually increasing with the aging of the society. As a result, it has become an important research topic how to diagnose AD early and give necessary treatment and training to AD patients, especially those with mild cognitive impairment(MCI), whose executive functions such as response inhibition, cognitive flexibility, attention switching and planning may display evident disorder and impairment. Unlike traditional paper tests and subjective assessments by the patient's relatives, this study adopts virtual reality(VR) technology to develop a novel diagnosis & assessment system, which uses head mounted display(HMD), game technology and sensors to generate an interactive and panoramic scenario—a virtual convenience store—for assessment of executive functions and memory. A variety of tasks of multi-layered difficulty-level hierarchy, such as memorizing a shopping list, looking for certain goods, and checking out, has been designed for customized and adaptive assessment, training, and treatment of MD. In the meantime, the study also records test-takers' performance data (including path and central-vision movement) in the process of all tasks for the development of a novel diagnosis & assessment method. Moreover, test-takers' technology acceptance is measured for assessing the elderly's subjective perception of new technology and discussing the topic of human-machine interaction. In the study, tests on 2 healthy adults have been completed, the system's functionality has been preliminarily verified, and test-takers' subjective perception of the system has been investigated.**

Keywords- virtual realit;, mild cognitive impairment; Alzheimer's Disease; executive function

I. INTRODUCTION

The percentage of the elderly in the population has been gradually increasing due to the progress of medical technology. In the meantime, it is estimated that the population of AD patients, which has also been expanding steadily, may experience explosive growth in the next ten years. In light of this, the early diagnosis of AD becomes even more important . In recent years, scientists has shifted their focus in clinical study to early diagnosis of AD from two aspects, i.e. normal aging and senile dementia. Mild cognitive impairment(MCI) has been recently used to define the two aspects.

Executive functions are high-level functions used to accomplish complicated tasks. Executive function disorders include attention deficit, planning, problem-solving, multi-task, monitoring and behavior control. Previous studies on MCI suggest that, compared to healthy control group, patients with MCI may have more executive disorders, especially in response inhibition, cognitive flexibility, attention switching and planning. Nowadays, MCI assessment mainly depends on paper tests, or subjective assessments by the patient's relatives, for example, whether the patient often forgets something, whether the patient knows his/her way home, and etc. Josman et al(2006) used a virtual market to test post-apoplectic patients and found that the virtual supermarket test requires strong planning ability, which is an important component of executive functions. It requires complicated executive functions to accomplish activities of daily living(ADLs). José-Antonio et al(2009) proposed the VIRCOG system(VIRtualCOGnitive system) which consists of two tasks, i.e. walking in the street and shopping in the supermarket, for rehabilitation of patients for ADLs.

VR is a technology which represents a great progress in human machine interaction. It can induce psychological immersion and high presence in users. Prashun et al(2010) investigated the effect of VR on the rehabilitation trend of post-apoplectic patients and pointed out the use of VR as a rehabilitation tool might achieve more intuitive and effective home-based rehabilitation at lower cost. Rosa and Luis(2000) proposed that the use of VR in cognitive rehabilitation might be more structurally focused and could follow current teaching trend to integrate various cognitive function rehabilitation strategies. The use of lifelike VR may narrow the gap between

978-1-4673-1666-8/12/$31.00 ©2012 IEEE

patients and ADLs and relieve their misgivings against errors. Moreover, the paper tests used in the past for assessment of executive functions are relatively simple and can assess one aspect only at a time; assessments with VR technology, however, resemble real-life experience better because they can simulate realistic environment and can get timely feedbacks. By adjusting training difficulty and multiple variables and increasing test complexity, executive functions can be tested more comprehensively.

Giuseppe Riva et al(2007) suggested that the application of VR technology is restrained because of the high installation cost and customization difficulty of VR equipment and lack of professional operators. In light of this, we reduce the cost and complexity of equipment as far as possible in this experiment and provide a script editing interface through which the doctor or the patient's relatives can select appropriate scripts according to rehabilitation strategies without worrying that construction of the system will cost a lot of money.

As far as planning, a component of executive functions, is concerned, Klinger and Marie et al designed a virtual action planning supermarket (VAP-S) which provides a test similar to the "test of shopping list" that requires a series of actions and can be used to analyze the actor's selection strategy and planning ability.

Based on this foundation and in light of the fact that the densely-populated Taiwan has a great number of convenience stores, we use VR technology to construct a virtual convenience store for executive function testing, assessment, and training. The tests include memorizing a shopping list, looking for certain goods, and checking out. The system will be tried on human subjects to verify its functionality and effectiveness. Meanwhile, the test-takers' technology acceptance and subjective perception will also be measured. The architecture of the study is as shown in Figure 1.

II. METHOD

A. SystemDesign

The system adopts a game engine called Unity to construct a virtual convenience store and uses HMD to display the virtual scenario (we also offer an alternative mode in which three screens are used for displaying a 120 degree scenario). The HMD is embedded with posture sensors which enable the displayed scenario to be refreshed continuously according to the test-taker's head movement and visual line direction; meanwhile, the test-taker uses a joystick to carry out movement and selection operations. Furthermore, a surround audio system is used to simulate 3-dimensional sound effects. The architecture of the system is as shown in Figure 2.

The tasks involve a 3-stage scenario: at first, the system will display a shopping list with the name(s) of 1-10 item(s) of goods(depending on the therapist's design), as shown in Figure 3, and the test-taker is required to memorize the content of the list; then, the test-taker will enter the store to look for and click to select the item(s) on the shopping list; the shopping list and a shopping cart list may/may not be displayed on the upper left corner of the screen (at the discretion of the controller according to the experiment's objectives); the shopping cart list displays the purchased goods. As shown in Figure 4, the test-taker can check out only after he/she has accomplished the shopping task as specified on the shopping list and there is no time limit for the shopping task.

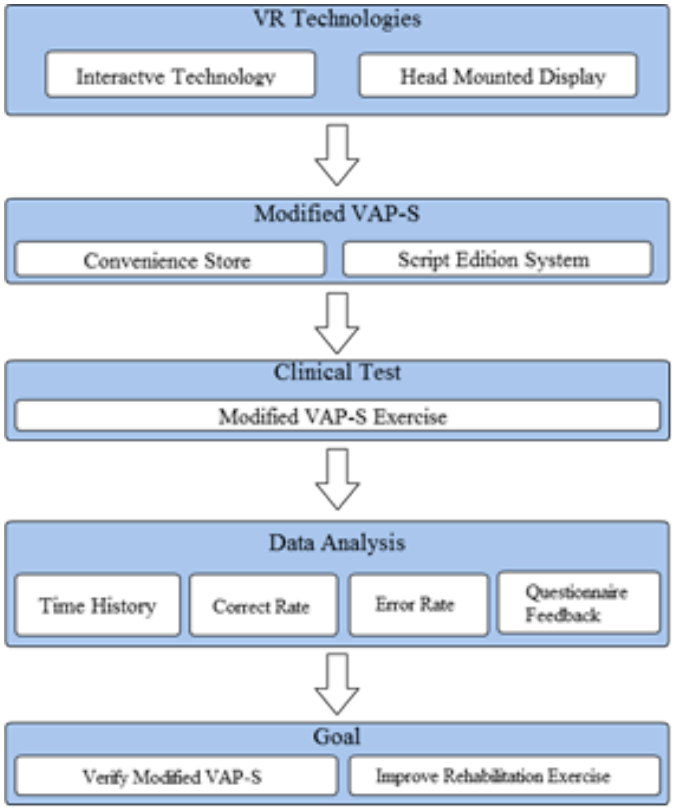

Figure 1. Research Chart

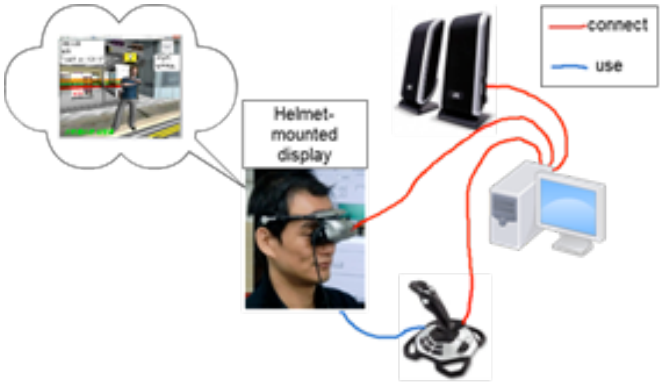

Figure 2. System Architecture

When all goods have been selected, click the cashier desk to check out. At the time of check-out, the test-taker must select the money (face value of bank notes and quantities) he/she is about to pay as shown in Figure 5. Situations of that the cashier gives the test-taker the wrong change may occur at

random; in such cases, the test-taker must check the change and correct any error as shown Figure 6.

Figure 3. Shopping list

Figure 4. Item search and selection

In this chapter, the design of the convenience store, including the test-takers and their background, the game, scripts design, experiment data collection, and the final questionnaire survey, is introduced.

B. Experiment

1) Subjects

It is estimated that a total of 90 senior subjects between the ages of 50 and 90 will be recruited for the experiment. 60 of the subjects will be senior people diagnosed with senile dementia by their doctor, the rest 30 subjects in the control group will be healthy people. The term "healthy" in this experiment is defined as "free of neurological diseases/mental disorders. Exclusion criteria for both groups include poor eyesight(for example: amblyopia or blind), motion disabilities

Figure 5. Payment system

Figure 6. Change system

which prevent the suffer from controlling the instrument (for example: apoplexy).

Subjects in the experimental group are mainly patients with senile dementia from the psychiatry clinic of a local hospital, while subjects in the control group are volunteers recruited from local communities.

All subjects will sign an informed consent for the experiment and will receive a simple background survey (e.g. medical history or spending habits investigation) before the tests.

Two normal people have been recruited to try the functionality of the system and have received a preliminary questionnaire survey before the experiment.

2) Procedure

Before the tests, the test-taker will receive a background survey and will be demonstrated how to operate the VR system for the tests. Once the test-taker get familiar with the operations, the tests will begin. During the tests, the test-taker

must follow the guide's instruction to purchase the required goods. After check-out, the test-taker must return to his/her original place to accomplish the task. The guide may specify the required goods by means of texts (showing the goods' name(s) only) or picture(s)(of the goods only). The tests are available in two modes, one with the shopping list displayed and the other without, and the test-taker must memorize the required goods if the shopping list is not displayed. Before each test begins, the experiment controller may decide at his/her discretion whether the required goods should be specified by means of texts or pictures, and whether it is necessary to display the shopping list or not. Once the tests come to an end, the test-taker will be required to fill out a feedback questionnaire to find out the usability of the system and the tests and the test-taker's technology acceptance. The experiment procedures are as shown in Figure 7.

Figure 7. Experiment Procedure

C. *Data Collection and Analysis*

1) *Background of Subjects*

Find out the subjects' spending habits , including (1) whether they have the habit of shopping or not; (2) the place(s) they frequent when go shopping (3) whether they prefer shopping alone or with someone else; and (4) their shopping frequency.

2) *Task Performance*

Record the following information: number of times of incorrect purchase; number of times of incorrect payment; correct/incorrect change checking; error rate and correct rate of purchase; correct rate and error rate of payment; and the time for accomplishing the task.

3) *Behavior History*

During the experiment, record the test-taker's location-time history data, the goods at which the test-taker has gazed, and whether the test-taker has selected a certain goods or not. With the location-time history data, the test-taker's movement path during the experiment can be plotted and the length of the path can be calculated. After analyzing these data, the planning strategies for executive functions and their merits and drawbacks can be determined, and the test-taker's executive function performance before and after using the system for a period of time can be compared to determine whether or not he/she has made progress.

4) *Questionnaire*

In order to analyze and measure the test-taker's subjective perception of the system's human machine interface, we request the test-taker to complete a feedback questionnaire after the experiment. Contents of the questionnaire include the test-taker's technology acceptance and the system's usability.

As the system adopts new technological equipment for interactive human-machine interface, we use Technology Acceptance Model(TAM) to measure the test-taker's acceptance. The TAM contains such measurements as Usefulness(A:1~2, 20; B:10,13), Ease of use, (A:3~4, 9~14 ; B:1~9, 11~12, 14~19, 22), Intention to use(A:15~19, 21 ; B:20~21) as well as Playfulness(A:5~8) and Presence(B:23~28). The questionnaire adopts a 5-point scale, in which a score of 1 point represents strongly disagree and a score of 5 points indicates strongly agree. For details of the questions, refer to Appendixes A &B.

III. DISCUSSION

In order to verify the system's functionality , we have recruited two people in advance to take the tests. After the testing, we collected the objective time-history data recorded by the system and the subjective data from the test-taker's questionnaire feedbacks. The test-taker's performance can be judged by the objective data as shown in Table 1; and his/her technology acceptance can also be found out from the subjective data as shown in Table 2.

Figure 8. Path

It can be seen from Table 2 that, as far as the average score for every factor in the 5-point scale questionnaire is concerned, all of the average scores are higher than 3 points, which suggests that every factor received positive comments. Three factors, i.e. Presence, Playfulness, and Intention to use, rank top 3 in term of scores.

IV. CONCLUSION

This study successfully developed and constructed an interactive and panoramic scenario—a virtual convenience store—for assessment of executive functions and memory by

using VR technology, head mounted display(HMD), game technology and sensors. A variety of tasks of multi-layered difficulty-level hierarchy, such as memorizing a shopping list, looking for certain goods, and checking out, has been designed for customized and adaptive assessment, training, and treatment of MD. In the meantime, the study also recorded the test-taker's performance data and history date of task execution(including path and central-vision movement) in full and measured the subjects' technology acceptance. In the study, tests on 2 healthy adults have been completed, the system's functionality has been preliminarily verified, and the subjects' subjective perception of the system has been investigated successfully. The results show that the subjects readily accept new technology and are willing to continue to use the system. In the future, large scale clinical trials will be carried out to further verify the system's medical effectiveness, and develop novel diagnosis assessment methods.

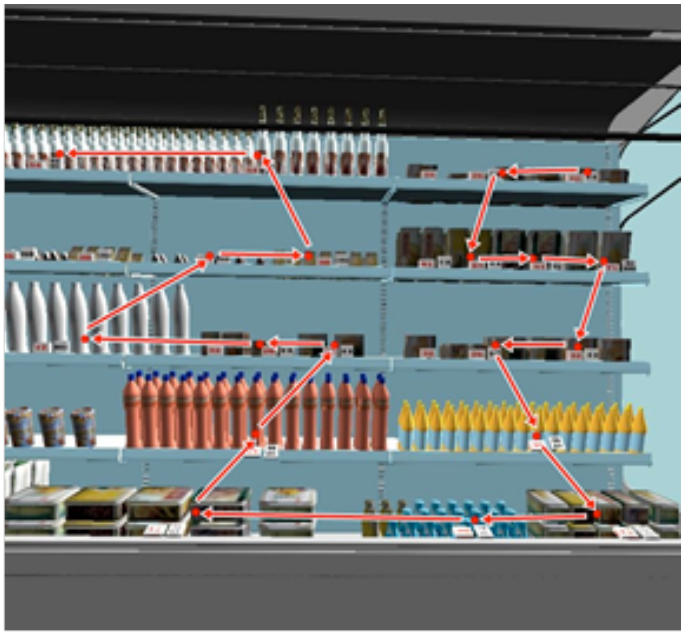

Figure 9. Central-vision movment

TABLE I. TASK PERFORMANCE

Shopping List		**Magazine Hamburger**
Search & Selection	**Total incorrect selection times**	**1**
	Total incorrect purchase times	**1**
Payment	**Total incorrect payment times**	**1**
	Incorrect change checking	**0**

TABLE II. QUESTIONNAIRE STATISTICS

Factor	**Mean value**
Usefulness	3.8
Ease of use	3.7
Intention to use	3.9
Playfulness	4.0
presence	4.4

ACKNOWLEDGMENTS

We would like to thank the researchers, teachers, and students who participated in the system design, implementation, and experiment. We are also grateful for the support of the National Science Council, Taiwan, under NSC 100-2221-E-008-043- & NSC 100-2631-S-008-001.

REFERENCES

[1] Werner P, Rabinowitz S, Klinger E, Korczyn AD, Josman N, "Use of the Virtual Action Planning Supermarket for the Diagnosis of Mild Cognitive Impairment A Preliminary Study", Dement Geriatr Cogn Disord 2009;27:301–309

[2] Moreira da Costa, R. M. E., Vidal de Carvalho, L. A., De Aragon, D. F., "Virtual reality in cognitive retraining", Advanced Learning Technologies, 2000.IWALT 2000.Proceedings. International Workshop on:221-224

[3] Josman, N., Hof, E., Klinger, E., Marie, R. M., Goldenberg, K., Weiss, P. L., Kizony, R.,"Performance within a virtual supermarket and its relationship to executive functions in post-stroke patients", Virtual Rehabilitation, 2006 International Workshop on:106-109

[4] Riva, Giuseppe, Gaggioli, Andrea, Villani, Daniela, Preziosa, Alessandra, Morganti, Francesca, Corsi, Riccardo, Faletti, Gianluca, Vezzadini, Luca, "A Free, Open-Source Virtual Reality Platform for the Rehabilitation of Cognitive and Psychological Disorders", Virtual Rehabilitation, 2007:159-163

[5] ozano, J. A., Gil-Gomez, J. A., Alcaniz, M., Chirivella, J., Ferri, J., "Activities of daily living in a virtual reality system for cognitive rehabilitation", Virtual Rehabilitation International Conference, 2009:205-205

[6] Raspelli, S., Carelli, L., Morganti, F., Riva, G., Weiss, P. L., Kizony, R., Katz, N., "Implementation of the multiple errand test in a NeuroVR-supermarket", Virtual Rehabilitation International Conference, 2009:210-210

[7] Prashun, P.Hadley, G.Gatzidis, C., Swain, I., "Investigating the Trend of Virtual Reality-Based Stroke Rehabilitation Systems", Information Visualisation (IV), 2010 14th International Conference:641-647