# An Innovative ADHD Assessment System Using Virtual Reality

Shih-Ching Yeh[1], Chia-Fen Tsai[2], Yao-Chung Fan[1], Pin-Chun Liu[1], Albert Rizzo[3]
shihchiy@csie.ncu.edu.tw fen0826@yahoo.com.tw 100522070@cc.ncu.edu.tw liu753951@hotmail.com arizzo@usc.edu
[1]Department of Computer Science & Information Engineering, National Central University, Taiwan
[2]Department of Psychiatry, Neurological Institute, Veterans General Hospital, Taiwan
[3]Institute for Creative Technologies, University of Southern California

**Abstract—Attention Deficit Hyperactivity Disorder (ADHD) has a prevalence of about 5% and may cause inferiority complex, personality disorders, interpersonal impediment, and even anti-social behaviors in affected children if not treated early. In the past, the diagnosis of ADHD patients mainly depended on paper tests or behavior scales. However, such tests are usually time-consuming and their application suffers from constraints of external conditions in terms of test content and test type. Through the application of VR technology including head mounted display(HMD), game technology and sensors, this study develops and constructs an interactive panoramic virtual classroom scenario in which a blackboard embedded with listening test, CPT test, executive test, and visual memory test specially designed for attention and executive functions is incorporated; moreover, this study also develops a new assessment & diagnosis system based on children's performance, behavior & reaction in the above-mentioned four tests through an enormous and systematic design of a battery of visual & auditory distractions of different intensity levels, durations, and sequence. The system developed in this study is used to carry out a pilot trial on healthy volunteers and its functionalities are confirmed by the test results.**

***Keywords-ADHD, virtual reality, executive function, memory***

## I. INTRODUCTION

### A. Study background

Attention Deficit Hyperactivity Disorder, usually abbreviated as ADHD, can be divided into three major categories featuring inattention, hyperactivity, or both. Almost five out of one hundred school-age children are suffering from ADHD. Results of previous studies show that ADHD patients have slightly poorer behavioral inhibition control than normal people and for this reason their behavioral competence performance is also poorer in many aspects (Barkley, 1997, 2000; Scheres et al., 2004). Most children with ADHD may experience gradual improvement in symptoms at their adolescence and about one third of children with ADHD may fully recover from the disorder or may slowly be relieved from the symptoms as they grow up. In spite of this, ADHD may nonetheless give rise to inferiority complex, personality disorders, interpersonal impediment, and even anti-social behaviors in affected children.

In the past, ADHD patients were commonly diagnosed through clinical treatment or with some behavior scales (Barkley,1991); however, these tests were time-consuming indeed and their data were particularly susceptible to the influence of extrinsic factors (Abikoff et al., 1993). Nowadays, ADHD is treated with various medications in conjunction with psychological counseling and behavioral therapies, including social skills training in daily life, family therapy or studying in school. However, such medications may cause adverse effects on children's physical and mental development in the future. In light of this, drug therapy is not recommended unless the patient's condition is serious. (yet to be confirmed; Dr. Tsai is consulted on this issue). The merit of VR system lies in that it can rapidly construct various lifelike living environment scenarios, such as the environment of a school. If the system is incorporated with various interactive tests, it would be even more helpful for the treatment of children with ADHD.

With the advance of technological progress, we gradually become capable of helping ADHD patients with hi-tech apparatuses and technologies. Throughout the world many scholars in the fields of healthcare & rehabilitation and first-line physicians and therapist adopt these technologies for clinical treatment of ADHD. Based on virtual reality, augmented reality, and other technologies, a wide variety of novel rehabilitation therapies and rehabilitation technologies are developed with user centered design concepts using the interactive modes and strategies provided by human machine interface, taken into consideration the system's usability, immersion, and perception in users. As every individual ADHD patient may face his/her unique situation, the development of a VR system offers the following advantages:1. the developed environment can be patient-specific and tailor-made to meet the patient's requirements; 2. the consistency between stimuli can be easily achieved by programming; 3. feedbacks can be collected right away from the patient and corrections can be made accordingly in a timely manner; 4. all behaviors and performance of the patient can be recorded in full in the VR system; 5. scenarios resembling real ones can be constructed for the patient at very low costs and easily reproduced, thus facilitating the system's promotion; and 6. the VR system can be programmed to be more entertaining, thereby motivating the patient to use the system. By contrast, fixed paper tests that can not be tailor-made are adopted in current medical environment. It takes a lot of time and much patience for the patients to go through the entire tests to get data for analysis. Moreover, it is difficult to construct identical learning environments in these tests which do not have instant modification functions. For this reason, ADHD patients find it boring to take these tedious paper tests and are reluctant to take such tests.

### B. *Relevant studies*

A VR system, the Virtual Reality Cognitive Performance Assessment Tool (VRCPAT)( Parsons TD et al., 2008), was used in the past as an aid to traditional tests. The VRCPAT employs a VR city, in which the test-taker is required to complete several tasks independently to assess his/her attention, memory, space perception, executive function, and etc. Originally, the tedious traditional paper and pencil test would take 90 minutes. But in the VR city, the test took only 15 minutes and collected data highly correlated to those collected with traditional test, thus significantly reducing the time spent by the test-taker on taking the test.

A previous study indicated that, the use of a VR classroom system can effectively determine whether a boy taking tests is suffering from ADHD or not (Parsons TD et al., 2007). In the study, 10 boys with ADHD and 10 control groups were placed in the VR classroom system. The test-takers were asked to wear a pair of VR glasses through which they found they were in a lifelike scenario consisting of virtual characters and objects such as teacher(s), desks and chairs, other students, and various distraction factors. The test-takers were then asked to complete a go/no-go task in the scenario. These researchers' study results might not be rigorous enough since the number of samples was a bit too few, nonetheless the architecture and process of their study can be of good reference value. Moreover, the study also pointed out that the children's intelligence level can work upon their scores in the designed tasks and for this reason the intelligence gap between groups should not be too wide. In light of the above-mentioned two points, we decide to expand the number of study subjects to 100 and incorporate into the VR system tests which will not be affected by intelligence levels in order to improve the ecological validity of the system designed by us, so that the results of our experiment would be more rigorous.

In addition, there were previous studies utilizing VR classroom system for comparison of children with ADHD and normal children. The test results of these studies which were carried out in the same virtual environment with HMD (Rizzo et al., 2006; Rizzo et al., 2000, 2003, 2004) also indicated that children with ADHD made poorer performance and got lower scores. This further demonstrates the practice of using a VR system for attention test is effective.

### C. *Study objectives*

*1)* To construct an interactive virtual classroom. The virtual scenario will be an ordinary classroom where there are desks and chairs, blackboard, projection screen, virtual students and teachers, and et cetera to simulate the classroom environment of the test-takers.

*2)* Based on the above-mentioned VR system, auditory and visual tests on attention and cognitive function, including listening test, CPT test, executive test, and visual memory test, will be incorporated and immersed into the virtual scenario. Meanwhile, HMD will be used to record the rotation orbit of the test-taker's head. During the tests, external distraction events will be added to generate environment distractions of different intensity levels for validation of the impact of distraction on the test-taker's attention and cognitive function.

*3)* After an analysis of the test results, whether the system can effectively identify ADHD patients or not will be validated and the system will be used for treatment of ADHD patients. Furthermore, the system will be compared with traditional paper test tools, confidence level will be tested, and the acceptability of virtual technology among test-takers will be measured.

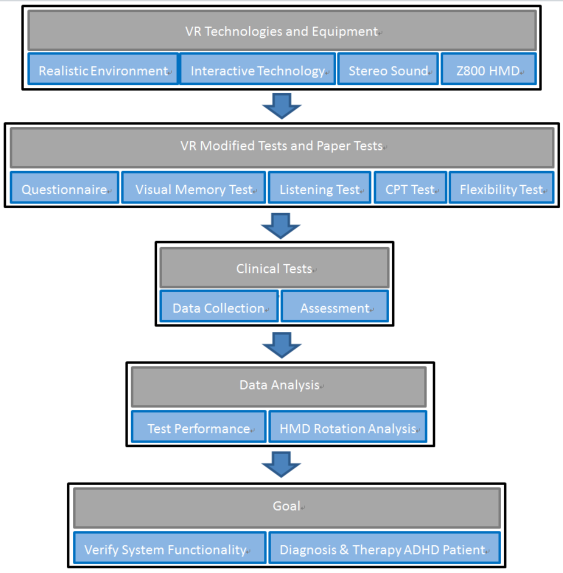

Figure 1.Study architecture

## II. STUDY METHOD

### A. *System design*

#### *1) VR classroom system*

##### *a) Construction of 3D virtual scenario*

The virtual scenario is developed with 3Dunity, a game engine. The most up-to-date version of the engine is 3.4. A virtual classroom with desks and chairs, other students, teacher, blackboard, projection screen, and et cetera is constructed to simulate an ordinary classroom.

Outside one side of the classroom there is a street with pavement, stores, and street view; outside the other side there are trees and a nature view. After the scenario is roughly constructed, use C# and Java script to program the behaviors of the added objects. For example, the students may walk around, the screen may display contents of a course or a test, and environmental sounds simulating those in a real scenario will also be added.

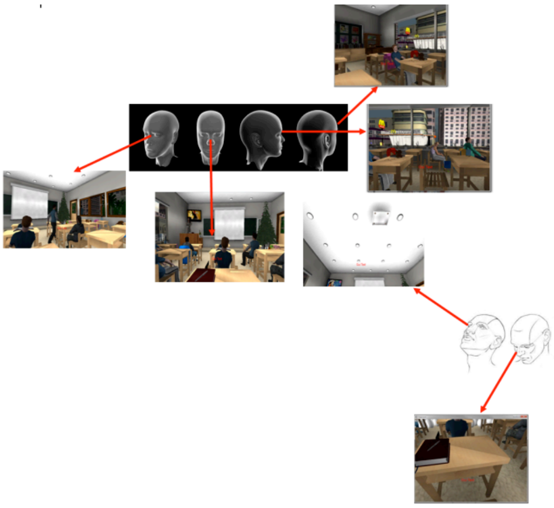

Figure 2. Scenes displayed after putting on the HMD

*b) Interactive design*

The interactive design between the test-taker and the virtual environment is to help the test-taker to immerse into the virtual environment, thereby improving the effectiveness of tests. It is planned that the system will use an HMD with embedded posture identifier to generate 360 degree 3D visual effects for the test-taker and effectively isolate the test-taker from the real environment. The field of vision will match the rotation posture of the test-taker's head to help the test-taker to immerse into the virtual environment.

In addition to capturing the test-taker's head rotation information with HMD, we also design an alternative experiment mode in which the test-taker's field of vision will be displayed on three computer screens to create an immersive feeling and the test-taker's eye movement information will be captured by an eye tracker.

*c) Environmental distraction design*

In order to correctly identify whether the test-taker is a ADHD patient or not, we design some environmental distraction factors. Visual part of the distraction factors includes:


Figure 3.Distractions from right side

(Walking teacher outside the classroom )
(Moving school bus outside the right side of the classroom )


Figure 4. Distractions from left side

(Moving car outside the left side of the classroom)
(Paper airplane flying pass the test-taker's right side/left side from behind)

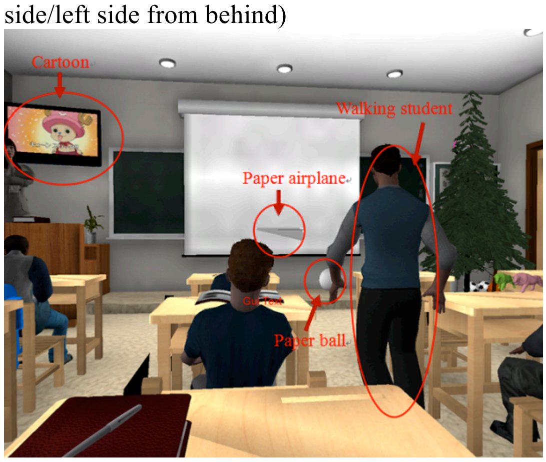


Figure 5. Distractions inside the classroom

(Paper balls thrown to the rostrum by students behind the test-taker)
(Cartoon program displayed on a TV set behind the teacher)
(Students walking through the test-taker's field of vision)

Auditory part of the distraction factors includes:
(1) Horn sounds of cars moving outside the classroom
(2) Sounds of rain and thunder outside the classroom
(3) Sneeze sounds of students nearby
(4) Dog barking sounds outside the classroom
(5) Sounds of the Cartoon program displayed on a TV set behind the teacher
The auditory distraction factors are so that the test-taker will be able to correctly identify which side (left side or right side) a sound is from

*d) Script editing system*

The script editing system enables the doctor to choose environmental distraction factors to be added for an individual patient before the latter immersing into the virtual scenario for simulated exercises of various distraction tests. Moreover, we have designed three different tests which can be selected through their corresponding shortcut keys in the scenario and the test data can be stored for the doctor's analysis after the tests.

*e) Hardware equipment*

HMD, features:

It is planned that the system will use an HMD with embedded posture identifier to generate 360 degree 3D visual effects for the test-taker and effectively isolate the test-taker from the real environment. The field of vision will match the rotation posture of the test-taker's head to help the test-taker to immerse into the virtual environment. .

Sound equipment:

In the classroom, the test-taker may hear various distraction sounds from all directions. During the experiment, these distraction sounds may come from sound sources in various directions or from the test-taker's virtual classmates' behaviors. We use surround sound equipment to meet these requirements.

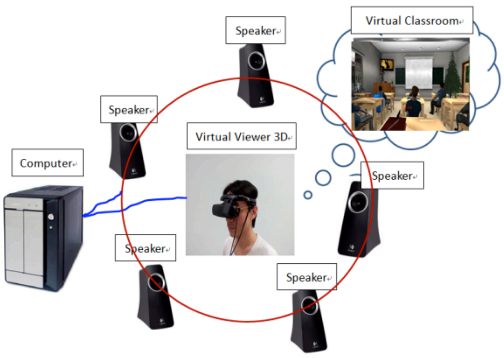


Figure 6. Schematic diagram of the system

*B. Test design*

*1)* Test 1 is a VR-CPT test, which was first published by Rizzo et al[6] with Digital Media Works (2002) (http://www.dmw.ca/) and later modified and localized by Yeh et al and students from National Central University. In the test, the test-taker is required to gaze directly at the center of the scenario where there is a projection screen on which various English letters keep emerging. The test-taker is asked to press down a button whenever the letter X appears. Various distraction events keep emerging throughout the testing process.

*2)* Test 2 is a flexibility executive functional test modified from a test developed by Taipei Veterans General Hospital. In the test, the test-taker is required to determine which one of the two graphs displayed meets a specific rule. If the test-taker thinks the right one does, he/she should press down the button corresponding to the right graph; if he/she thinks the left one does, he/she should press down the button corresponding to the left graph. The rule is such, the test-taker should select a graph in the order of "taper angle" → "rounded angle" →"taper angle" →"rounded angle" …and so on until the test ends. With regard to the definitions of "taper angle" and "rounded angle", they will be explained at the beginning of the test and samples of the graphs will also be available .

*3)* Test 3 is a listening test carried out in two stages. Stage 1: A figure (A) is set as the reference at the beginning. During the test, if the test-taker hears the figure A, he/she should press down a confirmation button. Stage 2: Two figures (A and B) are set as the references at the beginning. During the test, the test-taker should press down the confirmation button only if he/she hears figure A followed by figure B.

*4)* Test 4 is a visual memory test in which the test-taker has five seconds to memorize a graph displayed on the projection screen. Then the test-taker will be asked to decide which one of the five graphs is the one he/she had just seen and should press down a button correspondingly. Before any of the four tests begins, there will be a brief pretest helping the test-taker to get familiar with the test rules in order to avoid misunderstanding and consequent data errors.

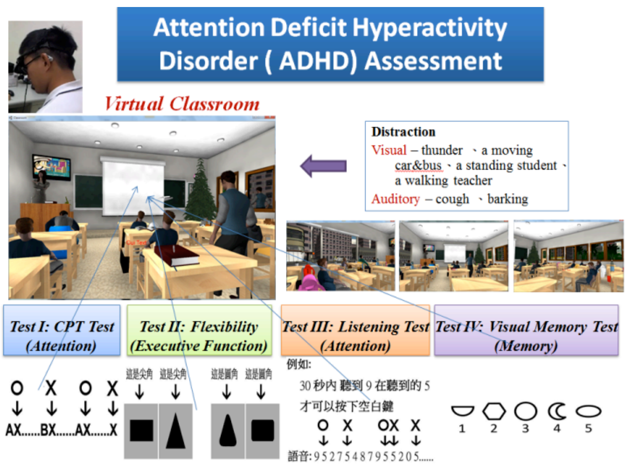


Figure 7. Scenarios the test-taker may see. The tests are displayed on the projection screen.

### *C. Experiment design*

*1) Subjects*

*a) Inclusion criteria:*

1.ADHD patients diagnosed by a physician (according to DSM-IV diagnosis criteria ); 2. Between the ages of 7-13; 3. Free from intellectual disability; 4.Free from other major congenital diseases, neurological diseases, or major mental disorders (e.g. epilepsy)history; 5. capable of following instructions cooperatively during the test; 6.subjects in the control group are health people of similar ages.

*b) Exclusion criteria:*

1. Those who refuse to sign a informed consent.

*c) Number of subjects :*

It is estimated that a total of 100 subjects will be included ( experimental group: 50 subjects; control group: 50 subjects).

*2) Experiment procedures*

*a) Study method :*

It is estimated that a total of 100 subjects will be recruited through purposive sampling for this study. 50 subjects will be recruited from the Child and Adolescent Psychiatry Clinic of Gandau Hospital for the experimental group(ADHD group), the rest 50 subjects in the control group will be the patients' healthy siblings or healthy children recruited from their community.

*b) Study tools :*

All subjects and their legal agents shall fill out an SNAP-IV rating scale and complete the operational assessments in the interactive VR classroom. Their correct rate, error rate, response time, and total time used at various stages will be recorded.

*c) Study procedures:*

The testing procedures of the study consist of two stages. Stage 1is for collecting basic information and filling out questionnaire(s) and will take about 15 minutes. Stage 2 will be carried out within four weeks after the completion of Stage 1. The test-takers will take cognitive tests in a virtual classroom for at least two passes, one for testing with distractions and one for testing without distractions. Each pass will take approximately 30 minutes.

### *D. Data types and analysis methods*

*a) Head posture data:*

The test-taker will put on an HMD and his/her head may turn to various directions during the testing process whenever an distraction event occurs in the scenario. If the test-taker does get distracted, that would suggest that the distraction event we constructed does work. From the captured head rotation information of the test-taker and the occurrence time of the distractions, we can deduce what distraction factors do affect the test-taker in the scenario.

*b) Test performance:*

Correct rate, error rate, response time at various stages, and the total time used. There are two error types recorded in the study. If the test-taker fails to press down a correct button, that would be referred to as a Type 1 error; If the test-taker presses down a wrong button, that would be referred to as a Type 2 error.

*c) Questionnaire scales :*

*(a) DSM-IV-based ADHD screener:*

The Diagnostic Rating Scale (DRS) uses a categorical rating approach to symptoms of ADHD. This questionnaire is widely accepted as a diagnostic tool with sensitivity of 70% to 90% for 6 positive answers (out of 9) in each section.10

*(b) Subjective feedback questionnaire (SFQ):*

The SFQ consists of 8 items assessing the participant's subjective feelings during a testing session.

## III. RESULTS AND DISCUSSION

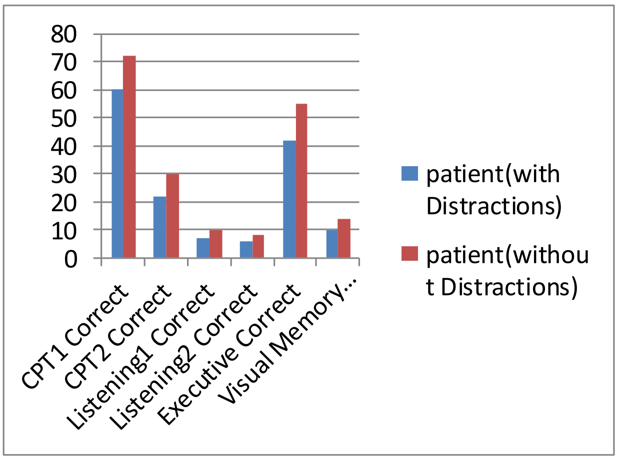


Table1.Patient1's result after doing all the experiment

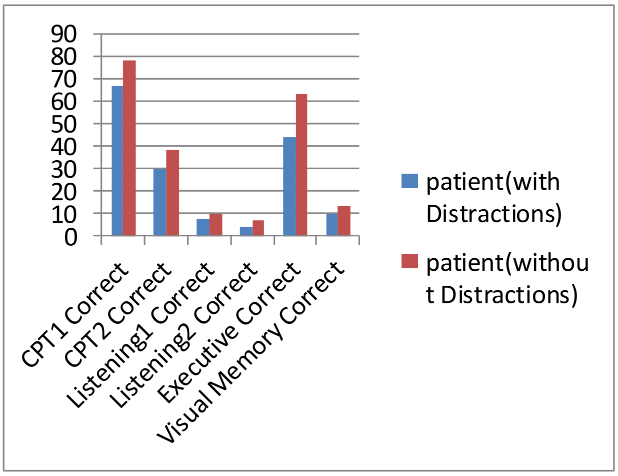


Table2. Patient2's result after doing all the experiment

So far, we have tested our system on two normal adults(23 years old) and plotted the test results into two broken line graphs for comparison . Each of the two adults took a full battery of the tests for two passes, one for testing without distractions and one for testing with all distractions. Every pass took about 30 minutes. It can be inferred from the test results that the distractions we designed did affect the test-takers' attention. Every individual test-taker received lower scores in all four tests with distractions than his/her scores in corresponding tests without distractions.

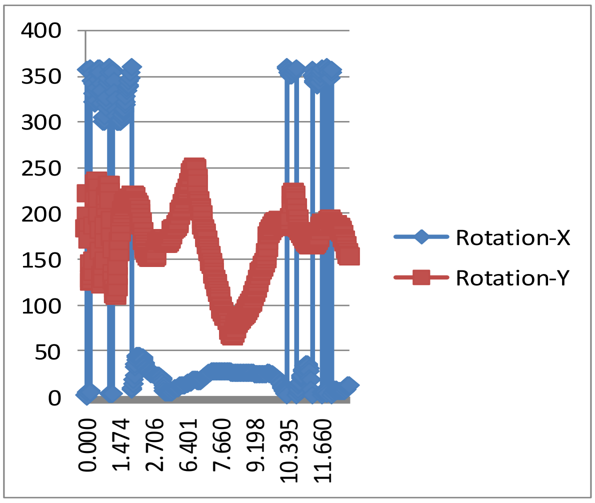


Table3. Head rotation information

Moreover, our program recorded the test-takers' head rotation information which, in conjunction with a timeline showing the occurrence of distractions, enabled us to determine whether the test-taker did rotate his/her head or not because of the distractions in the scenario during the tests.

## IV. CONCLUSION

This study successfully develops a novel VR technology based ADHD diagnosis & assessment system which is embedded with listening test, CPT test, executive test, and visual memory test specially designed for attention and executive function assessment and provided with natural human machine interactive mode(s) and panoramic function. Meanwhile, the study also designs a battery of visual and auditory distractions featuring enormous and systematic combination of distractions of various intensity levels, durations and sequence. Moreover, the study successfully carried out a pilot test in which the test-takers' performance, behavior & reaction in the above-mentioned four tests were measured. The results verified the functionality of the system in various aspects. In the future, a large scale clinical trial will be carried out on children with ADHD in order to further verify the medical effectiveness of this system.

## ACKNOWLEDGMENT

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] Abikoff, H., Courtney, M., Pelham, W. E. Jr., & Koplewicz, H. S. (1993). Teachers' ratings of disruptive behaviors: The influence of halo effects. Journal of Abnormal Child Psychology, 21, 519–533.

[2] Barkley, R. A. (1997). Attention-deficit/hyperactivity disorder, self-regulation, and time: Toward a more comprehensive theory. Journal of Developmental and Behavioral Pediatrics, 18, 271–279.

[3] Barkley, R. A. (1991). The ecological validity of laboratory and analogue assessment methods of ADHD symptoms. Journal of Abnormal Child Psychology, 19, 149–178.

[4] M. CarmenJuan a,n, DavidPe´ rez b : Using augmented and virtual reality for the development of acrophobic. Computers & Graphics 2010; 34: 756–766

[5] Parsons TD, Silva TM, Pair J, Rizzo AA: Virtual environment for assessment of neurocognitive functioning: virtual reality cognitive performance assessment test. Stud Health Technol Inform 2008; 132:351–356

[6] Parsons TD, Bowerly T, Buckwalter JG, et al: A controlled clinical comparison of attention performance in children with ADHD in a virtual reality classroom compared to standard neuropsychological methods. Child Neuropsychol 2007; 13: 363–381

[7] Rizzo, A., Buckwalter, J., Bowerly, T., van der Zaag, C., Humphrey, L., Neumann, U., et al. (2000).

[8] The virtual classroom: A virtual reality environment for the assessment and rehabilitation of attention deficits. Cyberpsychology & Behavior, 3, 483–499.

[9] Rizzo, A., Bowerly, T., Buckwalter, J., Shahabi, C., Kim, L., Sharifzadeh, M., et al. (2003).

[10] Virtual environments for the assessment of cognitive and functional abilities: Results from the virtual classroom and office. The Clinical Neuropsychologist, 17, 100–100.

[11] Rizzo, A., Bowerly, T., Shahabi, C., Buckwalter, J., Klimchuk, D., & Mitura, R. (2004).

[12] Diagnosing attention disorders in a virtual classroom. Computer, 37, 87–89.

[13] Rizzo, A., Bowerly, T., Buckwalter, J., Klimchuk, D., Mitura, R., & Parsons, T. (2006). A virtual

[14] reality scenario for all seasons: The virtual classroom. CNS Spectrums, 11, 35–44.