한국감성과학회지, Vol. 6, No. 3, pp. 55-62. September 2003

정신분열병 환자의 인지적/행동적 특성평가를 위한 가상현실시스템 구현

A Virtual Reality System for the Cognitive and Behavioral Assessment of Schizophrenia

이장한 · 조원근 · 김호성* · 구정훈 · 김재훈 · 김병년 · 김선일

한양대학교 의공학교실, 싸이코텍*

Jang-Han Lee, Won-Geun Cho, Ho-Sung Kim, Jung-Hun Ku,

Jae-Hun Kim, Byoung-Nyun Kim, Sun-I. Kim

Dept. of Biomedical Engineering, Hanyang University, Psychotech

Abstract : Patients with schizophrenia have thinking disorders such as delusion or hallucination, because they have a deficit in the ability which to systematize and integrate information. Therefore, they cannot integrate or systematize visual, auditory and tactile stimuli. In this study, we suggest a virtual reality system for the assessment of cognitive ability of schizophrenia patients, based on the brain multimodal integration model. The virtual reality system provides multimodal stimuli, such as visual and auditory stimuli, to the patient, and can evaluate the patient' s multimodal integration and working memory integration abilities by making the patient interpret and react to multimodal stimuli, which must be remembered for a given period of time. The clinical study showed that the virtual reality program developed is comparable to those of the WCST and the SPM.

Key words : Schizophrenia, Virtual Reality, Multimodal stimuli, Working memory

요 약 : 정신분열병은 망상이나 환각과 같은 양성증상과 감정적 둔마와 같은 음성증상이 대표적인 사고장애로서 외부입력 정보를 통합하거나 체계적으로 처리하는 능력이 매우 부족하다. 즉, 정신분열병 환자는 시각, 청각, 촉각 등의 자극을 종합하고 통합하여 인지하지 못한다. 본 연구에서는 뇌 인지 통합 모델(Brain Multimodal Integration Model)에 기반하여 정신분열병 환자의 인지 능력을 측정하기 위한 가상현실시스템을 제안한다. 정신분열병 환자의 지각, 인지, 운동능력을 측정하기 위한 가상현실시스템은 환자에게 시각과 청각의 멀티모달 자극을 제시하여, 환자로 하여금 일정시간 동안 자극을 기억하고 처리하여 주어진 과제를 수행하도록 하였다. 수행 결과를 통해 환자의 멀티모달 자극 통합능력 및 작업기억 통합능력, 네비게이션 능력을 평가한다. 임상연구를 통해 개발된 가상현실시스템을 WCST과 같은 기존 검사방법들과 비교하여 검증하였는데, 가상현실로 측정한 파라미터와 WCST의 파라미터 및 SPM 점수 사이에 매우 유의미한 상관관계를 보여 가상현실시스템의 유용성을 확인할 수 있었다.

주제어 : 정신분열병, 가상현실, 멀티모달 자극, 작업기억

교신저자 : 김선일

한양대학교 의공학교실 CAVE(Cognitive Agent in Virtual Environment) 연구실

주소 : 133-605, 서울시 성동구 성동우체국 사서함 55

전화 : +82-2-2290-8280 FAX : +82-2-2296-5943

E-mail : sunkim@hanyang.ac.kr

1. Introduction

Schizophrenia is one of the most devastating disorders in psychiatry, as it seriously affects higher mental functions, such as thinking, feeling, and perceiving [12]. Many investigators have described the fundamental deficit in schizophrenia patients on a psychological level as a disconnection between thoughts and action, or as deficits of "willed action"[6], the failure of inhibition [5,16], an inability to use context [4, 5], a distortion of the reinforcement of adaptive behavior [7], cognitive dysmetria [1], or as deficient executive function [17] or sensori-motor gating [2].

A recent study reported that the hierarchical organization of the brain can be schematized as a centrifugal arrangement from transmodal to more unimodal systems and regions [8]. These organizations are at the basis of coherent mental functions, and bind all information processes, memories, concepts and emotional sensations into a coherent integrated and united experience of reality.

Schizophrenia may be re-conceptualized as disturbances in the multiple constraint organization between and within neurological subsystems in the brain. The symptoms of schizophrenia involve a breakdown of one's coherent integrated and united experience of reality [13]. Research has been conducted to assess multimodal integration ability in schizophrenia based on the brain multimodal integration model by measuring EEG[14].

However, the current methods for schizophrenia diagnosis donot consider the patient's multi information integration ability. Currently, we could be measuring lower cognitive ability than normal when diagnosing schizophrenia using existing tests, such as the Vienna test, the Wechsler memory test and the Span of Apprehension task [11,10]. Whilst this research result has shown the lack of single cognitive functions, it cannot measure synthetic cognitive and integrative ability.

Virtual reality technology can provide various stimuli at the same time in a virtual environment and force the user to interact. It provides visual and auditory stimuli as well as spatial cognitive stimuli [9]. Virtual reality (VR) is a set of computer technologies, which when combined, provide an interactive interface to a computer generated world. VR technology combines real time computer graphics, body tracking devices, visual displays, and other sensory input devices and immerse a participant in a computer generated virtual environment. In this environment, the individual can see, hear and navigate in a dynamically changing scenario in which he participates as an active player by modifying the environment according to his interventions. This technology provides such a convincing interface that the user believes he is actually in the three-dimensional computer-generated space.

VR has a great potential both for neuropsychological assessment and for cognitive rehabilitation. Already a small number of research groups are experimenting with VR testing for cognitive rehabilitation [3]. Traditional neuropsychological testing methods are limited to measurements of specific theoretically predetermined functions, such as short-term memory or spatial orientation. Given the need to administer these tests in controlled environments, they are often highly contrived

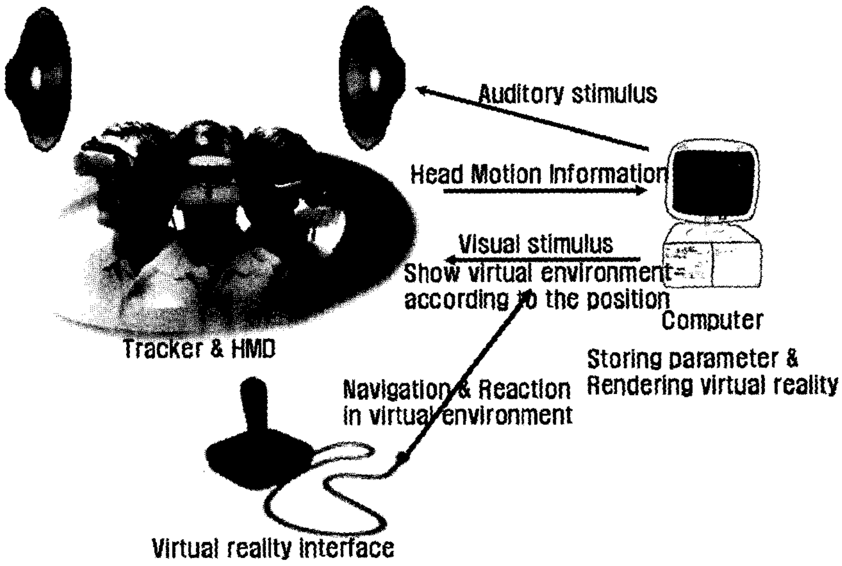

Figure 1. Hardware for Virtual Reality

and lack ecological validity, or any straightforward translation to everyday functioning [8]. VR enables subjects to be immersed in complex environments, which simulate real world events, and which challenge mental functions in a more ecologically realistic manner. While existing neuropsychological tests obviously measure some brain mediated behavior related to the patient's ability to perform in an "everyday" functional environment, VR could enable to be tested in ecologically valid situations. Whereas the quantification of results in traditional testing are restricted to predetermined cognitive dimensions, with VR technology, many more aspects of a subject's responses can be quantified. Information on latency, solution strategy and visual field preferences, etc. could be quantified. VR can be used to immerse subjects in situations where complex responses are required, and the responses elicited can then be measured [8].

Because of these characteristics, virtual reality technology can be utilized as an instrument that provides a multimodal stimulus. In this study, we suggest a virtual reality system for the assessment of cognitive ability based on the brain multimodal integration model and investigated its validation. The virtual reality system provides multimodal visual and auditory stimulus to the subject, which may be used to evaluate the subject's multimodal integration and working memory integration abilities by making the subject interpret and react to multimodal stimuli and remember for a given period of time.

2. Method

2.1 System

The developed Virtual Reality System consists of a Pentium IV PC, a DirectX 3D Accelerator VGA Card, a Head Mount Display (HMD, i-visor

DH- 4400VPD), a 3DOF Position sensor (Intertrax2), and a joystick which canbe vibrated. The PC with 3D Accelerator VGA Card generates a real-time virtual images that the subject must navigate. The position sensor transfers the subject' s head orientation data to the computer, and the joystick provides the means to navigate the virtual environment.

2.2 Virtual Environment

The Virtual Environment consists of rooms, which look like Egyptial pyramids, with 3 doors apiece, and which are linked by corridors. Every door has a colored shape on its surface and a sound is played when subject looks at the door. In every room, the subject should choose one door, if the wrong door is chosen, a vibration signal is given to indicate a mistake, but the door opens anyway. Rules can be changed during the task, to increase the difficulty level. The corridors contain avatars-mummies, obstacles that have to be avoided. The difficulty level is associated by the number of times the rules are changed during the course of the game, e.g., by the length and the crowdedness of the corridors. The doors in each room are assigned features that allow rule to be figured out based on a previous decision.

2.3 Tasks in Virtual Environment

During one task, the subject passes through 30 rooms (in about 20 min). The door' s task is based on the Wisconsin Card Sorting Test (WCST) however, it differs from the WCST in that it presents an integrated form of auditory and visual stimuli. The subject has to get out of the pyramid with doors, which behave in a Wisconsin card fashion. The doors have 3 features a shape (triangle, square or circle), a color (red, green or blue) and a sound. The rule for door opening is a combination of 2 features. The subject has to figure out and use the door-opening rule, and the rule changes his/her experience of the Virtual Environment.

2.4 Procedures

15 patients and 18 normal subjects participated in this experiment. Before the experiment, subjects were asked to complete a form containing name, age, job, education and so on, and were tested using three psychological tests (SPM, WCST, and K-MMSE). The subjects were then given virtual reality training until they became familiar with virtual reality interfaces and the virtual environment, and understood the nature of the task and the concept of the integrated rule. Patients and

Table 1. Parameters from VR for Cognitive Assessment System

Parameter	Method
Navigation	• Time to pass corridor • Number to collide the avatar and wall
Avoiding distractors	• Avoiding the avatar in corridor
Opening door performance	• Number to choose correct door in room • Time to be aware of the rule

normal subjects were divided by two groups according to rule change number. One group experienced 4 changes, and the other two changes whilst navigating the 30 virtual rooms. All subjects experienced empty and crowded corridors.

2.5 Cognitive Function Measurement

This system measures various parameters while a patient experiences virtual reality. As shown in the table, we measured the number of correct door choices, the time to find out a rule, the number of collision with avatars and walls, and the time to transit a corridor. We assessed and analyzed the following abilities: spatial visual motor integration, auditory motor reflexive integration, visual recognition motor reflexive integration, visual auditory integration and auditory visual working memory integration.

3. Results

Figure 2 shows a state, which provides a multimodal stimulus in a three door room. Figure 2(Left) shows the activating door state, which provides an auditory stimulus when a patient looks at the door. Figure 2(Right) shows a door leading to a corridor after a patient has looked around the room and selected the doors.

Figure 3 shows the state requiring movement to the next room in the corridor. Avatars

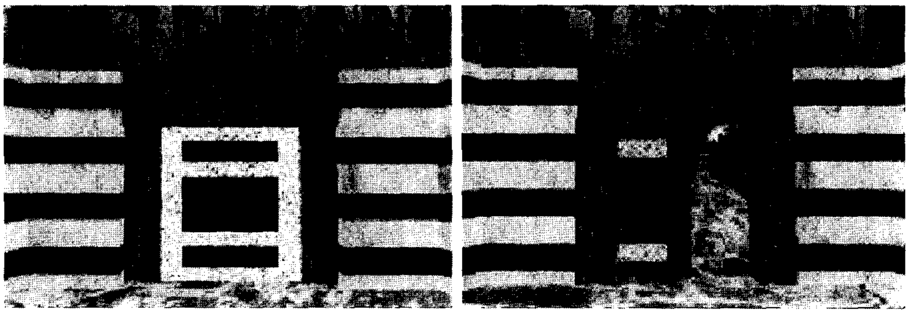

Figure 2. Virtual room for the assessment of cognitive ability

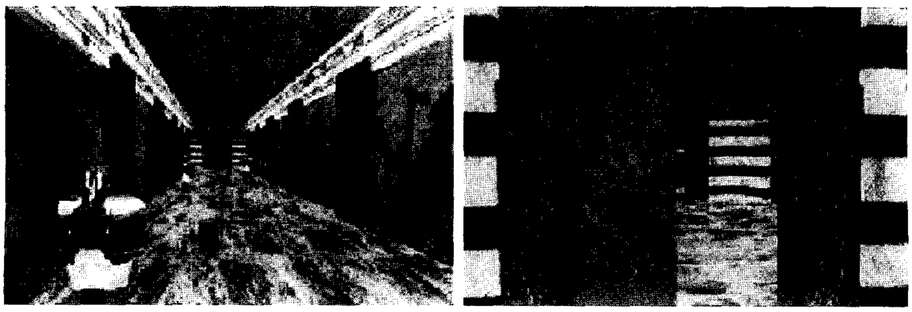

Figure 3. Virtual corridor for assessment of cognitive ability

Table 2. Results using VR parameters, and by SPM and WCST

		Patient (N=15)	Normal (N=18)	t value (p)
VR parameters (No. of avatar : 0)	No. of trials	27.47 (4.42)	24.72 (4.74)	1.707
	% of correct answer (%)	56.74 (14.38)	63.65 (14.82)	-1.353
	level	3.49 (1.45)	4.74 (0.62)	-3.507**
	time in rooms (s)	10.56 (6.88)	5.655 (1.494)	2.950*
	time in corridor (s)	10.28 (1.23)	8.38 (1.05)	4.761
	% of collision with wall (%)	23.86 (24.00)	19.29 (30.39)	0.472
VR parameters (No. of avatar : 6)	No. of trials	27.07 (4.18)	23.89 (4.96)	1.963
	% of correct answer (%)	55.43 (19.53)	65.75 (16.42)	-1.650
	level	3.78 (1.87)	4.63 (0.74)	-1.779**
	time in rooms (s)	8.21 (3.40)	5.07 (1.09)	3.702*
	time in corridor (s)	12.08 (3.72)	8.59 (1.41)	3.682
	% of collision with wall (%)	25.68 (26.57)	32.37 (61.33)	-0.392
	% of collision with avatar (%)	8.83 (13.33)	1.62 (2.98)	2.235**
SPM score	total	40 (11.95)	45.39 (3.43)	-1.83**
WCST parameters	No. of trials	111.8 (20.05)	86.94 (16.68)	3.889
	correct (%)	69.87 (12.17)	69.83 (8.95)	0.009
	errors (%)	35.27 (16.26)	18.39 (9.29)	3.737*
	categories completed	4.07 (2.34)	5.67 (1.41)	-2.419**
	trials to complete 1st category	36.07 (36.16)	19.89 (25.70)	1.499

* $p<.05$, ** $p<.01$

obstruct the patient and increase the transit time. The number of avatars was increased dependent on level.

After comparing the patient group and normal group, the results showed the level of difficulty achieved by VR testing ($t=-3.507$, $p<.01$), the average time spent in the virtual rooms ($t=2.950$, $p<.05$) in a session with empty corridor, and the average time in virtual rooms ($t=3.702$, $p<.05$) and the number of collision with avatars ($t=2.235$, $p<.01$) when 6 avatars were positioned in the virtual corridors were significant. In addition, the SPM scores ($t=-1.83$, $p<.01$) and the percentage of errors ($t=3.737$, $p<.05$) and the categories completed ($t=-2.419$, $p<.05$) in WCST were significantly different between the two groups.

The Correlations between VR and WCST parameters are shown. The level, the average time in rooms and the average time in corridor when the number of avatars is 0 and 6 were significantly correlated with WCST parameters. In addition, the number of trials with 0 avatars and the percentage of correct answers were also correlated with WCST parameters (See Table 3). In addition, the SPM scores were found to be correlated with the number of trials ($r=-0.415$, $p<.05$) and the level of difficulty ($r=0.528$, $p<.01$) in 0 avatars session.

Table 3. Correlations among VR and WCST parameters

	VR parameters	WCST parameters	r
No. of avatar: 0	No. of trials	No.. of trials	0.373*
	level	No. of trials	-0.540**
		Errors (%)	-0.491**
		categories completed	0.350*
	time in rooms	No. of trials	0.386*
		correct answer(%)	0.394*
	time in corridors	No. of trials	0.360*
No. of avatar: 6	level	No. of trials	-0.518**
		Errors (%)	-0.450**
		categories completed	0.462**
		trials to complete 1st category	-0.463**
	correct answer(%)	No. of trials	-0.454**
		Errors (%)	-0.379*
	time in rooms	No. of trials	0.399*
	time in corridors	No.. of trials	0.521**
		errors (%)	0.467**

* p<.05, ** p<.01

4. Discussion

In this study, we describe a virtual reality system, which was developed for the assessment of cognitive ability in schizophrenia, based on the brain multimodal integration model. The virtual reality system provides multimodal stimuli, such as a visual and auditory stimulus to the subject, which can be used to evaluate the subject's multimodal integration and working memory integration abilities by making the subjectinterpret and react to multimodal stimuli and remember details for a given period of time.

Using this system the patient navigates a virtual environment and performs tasks by integrating and remembering multimodal stimuli, such as visual and auditory stimuli. The system allows the assessment of the cognitive ability of a patient based on performance, and it is supported by the knowledge of the VR parameters that are significantly correlated with SPM and WCST, which are commonly used for neuropsychological testing.

The VR could provide a patient with various stimuli in the an immersive environment and allow the assessment of cognitive ability, and the identification of the relationships between cognitive functions.

Acknowledgement

This study was funded by a grant of the Korea Health 21 R&D Project, Ministry of Health & Welfare, Republic of Korea. (02-PJ1-PG11-VN01-SV03-0060).

References

[1] Andreasen, N.C.(1997). Linking mind and brain in the study of mental illnesses: A project for a scientific psychopathology. *Science*, 275, 1586-1588.

[2] Braff, D.L., & Geyer, G.C.(1992). Gating and habituation of the startle reflex in schizophrenic patients. *Arch Gen Psychiatry*, 49, 206-215.

[3] Christiansen, C., Abreu, B., Ottenbacher, K., Huffman, K., Masel, B., & Culpepper, R. (1998). Task performance in virtual environments used for cognitive rehabilitation after traumatic brain injury. *Arch Phys Med Rehabil*, 79(8), 888-892.

[4] Cohen, J.D., & Servan-Schreiber, D.(1992). Context, cortex, and dopamine: A connectionist approach to behavior and biology in schizophrenia. *Psychological Review*, 82, 407-428.

[5] Cohen, J.D., Braver, T.S., & O' reilly, R.C.(1996). A computational approach to prefrontal cortex, cognitive control, and schizophrenia: Recent developments and current challenges. *Phil. Trans. R. Soc. Lond*, 1515-1527.

[6] Frith, C.D., Friston, K.J., Liddle, P.F., & Frackowiak, R.S.J.(1991). Willed action and the prefrontal cortex in man: A study with PET. *Proceeding of the Royal Society of London*, 244, 241-246.

[7] Frith, C.D.(1992). *The Cognitive Neuropsychology of Schizophrenia*. Sussex UK: Lawrence Erlbaum.

[8] Gemma, A.C., Peter, C.H., Susan, D.I., & Michael J.B.(2001). Detection of Audio-visual integration sites in humans by application of electrophysiological criteria to the BOLD effect. *NeuroImage*, 14, 427-438.

[9] George, V.P.(2002). *Handbook of Virtual Environments Design, Implement and Applications*. New Jersey, LEA Inc.

[10] Kim, C.K.(2001). Relations among social functioning, psychopathology and attentional deficits in schizophrenic outpatients. *J Korean Neuropsychiatr Assoc*, 139, 100-112.

[11] Lee, H.S.(1998). Effects of cognitive differentiation training of integrated psycho-logical therapy to the basic cognitive functions in schizophrenic patients. *J Korean Neuropsychiatr Assoc*, 57, 801-810.

[12] Park, J.I.(2000). Direct and indirect cost of treating out-patients with schizophrenia in Korea. *J Korean Neuropsychiatr Assoc*, 39, 580-588.

[13] Peled, A.(1999). Multiple constraint organization in the brain: A theory for schizophrenia. *Brain Research Bulletin*, 49, 245-250.

[14] Peled, A.(2001). Functional connectivity and working memory in schizophrenia: An EEG study. *Intern J Neuroscience*, 106, 47-61.

[15] Rizzo, A.A., & Buckwalter, J.G.(1997). Virtual reality and cognitive assessment and rehabilitation: The state of the art. *Stud Health Technol Inform*, 44, 123-45.

[16] Spitzer, M., Braum, U., Hermle, L., & Maier, S.(1993). Associative semantic network dysfunction in thought-disordered schizophrenic patients: Direct evidence from indirect semantic priming. *Journal of Biological Psychiatry*, 34, 864-877.

[17] Weinberger, D.R.(1987). Implications of normal brain development for the pathogenesis of schizophrenia. *Archives of General Psychiatry*, 44, 660-669.