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A Virtual Environment for Investigating Schizophrenic Patients' Characteristics: Assessment of Cognitive and Navigation Ability

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ABSTRACT

Patients with schizophrenia have thinking disorders such as delusions or hallucinations because they have a deficit in the ability to systematize and integrate information. Therefore, they cannot integrate or systematize visual, auditory, and tactile stimuli. The multimodal integration model of the brain can provide a theoretical background from which one can approach multimodal stimulus integration. In this study, we suggest a virtual reality system for the multi-modal assessment of cognitive ability of schizophrenia patients. The virtual reality system can provide 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 Wisconsin Card Sorting Test (WCST) and the Standard Progressive Matrices (SPM), and it provides some information related to the schizophrenic patients' behavior in 3D virtual environment.

INTRODUCTION

SCHIZOPHRENIA IS ONE of the most devastating disorders in psychiatry, as it seriously affects higher mental functions, such as thinking, feeling, and perceiving.[1] 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,"[2] the failure of inhibition,[3,4] an inability to use context,[4,5] a distortion of the reinforcement of adaptive behavior,[6] cognitive dysmetria,[7] or as deficient executive function[8] or sensorimotor gating.[9]

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.[10] 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 reconceptualized 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.[11] Research has been conducted

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to assess multimodal integration ability in schizophrenia based on the brain multimodal integration model by measuring EEG.[12]

However, the current methods for schizophrenia diagnosis do not consider the patient's multi-information integration ability. Currently, many researchers reported that the schizophrenic patients have lower cognitive ability than normal when diagnosing them using existing tests, such as the Vienna test, the Wechsler memory test, and the Span of Apprehension task.[13,14] This research has shown the lack of cognitive functions in processing unimodal information, but it could not measure synthetic cognitive and integrative ability.

Virtual reality (VR) 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.[15] 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.[16] 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 and lack ecological validity, or any straightforward translation to everyday functioning.[17] 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 cognition 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.[17]

Because of these characteristics, VR technology can be utilized as an instrument that provides a multimodal stimulus. In this study, we suggest a VR system for the assessment of cognitive ability based on the brain multimodal integration model and investigated its validation. The VR 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 to remember these for a given period of time.

METHOD

System

The developed VR 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 can be 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 (Fig. 1).

Virtual environment

The virtual environment consists of rooms, which look like Egyptian pyramids, with three doors in each. The rooms are linked by corridors (Fig. 2).

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 must 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 rules to be figured out based on a previous decision.

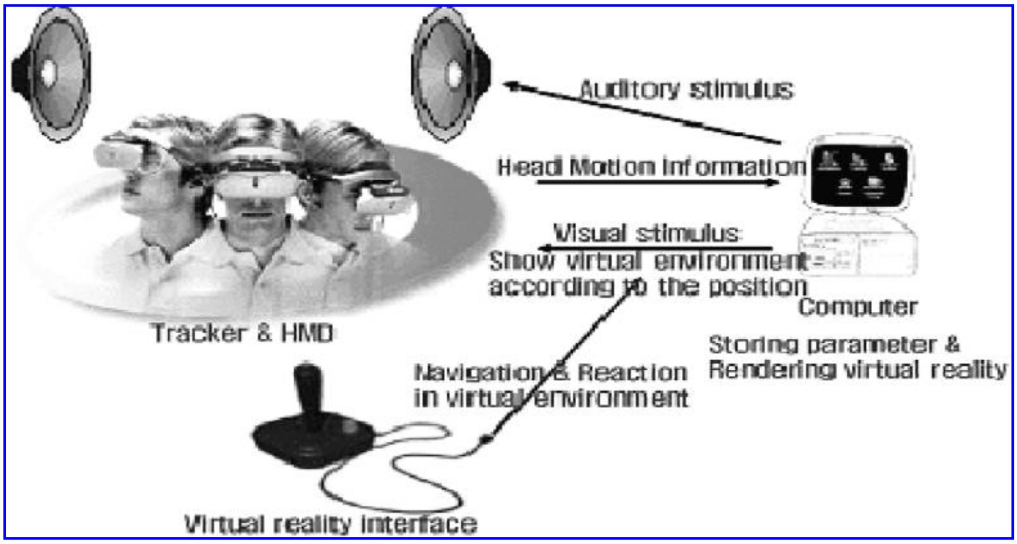

FIG. 1. Hardware for VR.

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 three 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 two features. The subject has to figure out and use the door-opening rule, and the rule is changed when subject get a several consequence correct answer.

Subjects

Subjects are composed of 13 patients (8 male and 5 female) and 13 controls (6 male and 7 female) (Table 1). The patients' mean duration of prevalence was 5.5 (SD 4.5) years and mean frequency of hospitalization was 2.4 (SD 1.7) times. Their total PANS Score was 92.2 (SD 22.56), the negative and positive PANS score were 23.3 (SD 6.81) and 22.5 (SD 8.16) respectively.

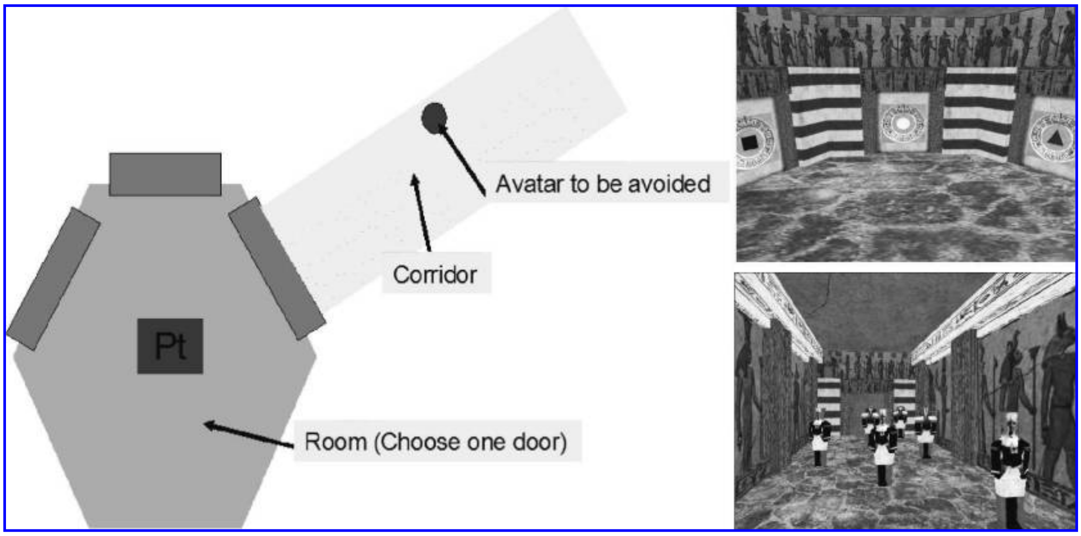

FIG. 2. Virtual environment.

TABLE 1. SUBJECT'S BRIEF PROFILE

	Patients	*Controls*
No. of subjects	13	13
Age	30.07 (SD 2.56)	27.84 (SD 3.43)
Sex	M: 8, F: 5	M: 6, F: 7

Experimental design

We used repeated measure design for our study. Rule changes occurred whenever the subjects got three consequence correct answer and the number of distractors in corridor was set at six (Table 2).

Procedures

Before the experiment, subjects were asked to complete a form containing name, age, job, education, etc., and were tested using three psychological tests (SPM, WCST, and K-MMSE). The subjects were then given VR training until they became familiar with VR interface and the virtual environment, and understood the nature of the task and the concept of the integrated rule. Patients and normal subjects experienced VR three-dimensional without avatars first, then with them.

Analysis

In order to compare with WCST, two indexes were picked by factor analysis. One is related to the rule-finding performance and the other is the perseveration index (Table 3).

We investigated the correlations between VR parameters and these two indexes to pick up the VR parameters which are highly correlated with each index. We got a navigation performance index by a factor analysis.

Parameters in virtual environment

This system measured various parameters while a subject experienced in VR. As shown Table 4, we measured the number of correct door choices, the time to understand a rule, the number of collision with avatars and walls, and the time to transit a corridor. We assessed and analyzed the following abilities: opening door performance, and navigation ability in 3D environment. The opening door performance was divided by two indexes which are correlated with WCST.

TABLE 2. EXPERIMENT DESIGN

Patients (N=13, age=30.07)		*Control (N=13, age=27.84)*	
Distractors		*Distractors*	
No	Yes	No	Yes

TABLE 3. INDEXES OF WISCONSIN CARD SORTING TASK

Factors of Index	*Coefficients*
Related rule finding	
Index = $0.350 \times [1] - 0.387 \times [2] + 0.366 \times [3]$	
[1] Non perseveration errors	0.350
[2] of completed categories	−0.387
[3] of 1st completed	0.366
Related perseveration response	
index = $0.350 \times [1] + 0.354 \times [2] + 0.333 \times [3]$	
[1] Perseveration response	0.350
[2] Perseveration errors	0.354
[3] Errors	0.333

RESULTS

There are some correlations between VR indexes and WCST indexes as shown in Table 5. Especially, There are more correlations in a condition with distractors. Table 6 shows the correlations between VR indexes and SPM score.

Figure 3 shows the overall result of opening door performance. In all scores, the control group was better than patients with and without distractors. Scores decreased with distractors in both groups.

There is a main effect between patient and control group in both index score [rule finding performance index: $F(1,24)=7.455, p<.05$], and perseverance index [$F(1,24)=6.312$, $p<.05$]. However, the rule finding performance index did not represent the interaction effect [$F(1,24)=0.004$, $p=.952$], while perseverance index did [$F(1,24)= 7.278$, $p<.05$]. So, we can say that the perseverance characteristic of schizophrenic patients can be seen more easily in the situation with 3D distractors (Figs. 4 and 5).

The navigation index showed the patients group has poorer navigation performance. Although there is no interaction effects, there is a tendency for patients' group to have poorer navigation performance with 3D distractors compared to the control group (Fig. 6).

TABLE 4. PARAMETERS FROM VR FOR COGNITIVE ASSESSMENT SYSTEM

Index	*Parameter*	*r*	*Coefficient*
Opening door	Related rule finding performance		
performance =	= 0.291 × [1] + 0.260 × [2] + 0.289 × [3] – 0.263 × [4]		
rule finding −	[1] Correct answer		
perseverance	[2] The level completed	−.653**	0.291
	[3] (A+B) Type response	−.580**	0.260
	[4] (F+G) Type response	−.594**	0.289
		.650**	−0.263
	Related perseveration response		
	= [1] + [2]		
	[1] E type response		
	[2] of collision wall and avatars	.441*	
		.510*	
Navigation rate			
= 0.286 × [1] +	[1] of collision with wall and avatars		0.286
0.362 × [2] +	[2] Time to completed the session		
0.304 × [3] + 0.265 × [4]	[3] Time in corridors		0.362
	[4] Time in rooms		0.304
			0.265

A+B Type response is to choose two consequence correct doors. F+G Type response is to choose two consequence incorrect doors. E Type response is to choose a door have no possibility to be correct answer *r* value represents a correlation with VR parameters and WCST total index (*p<0.05, **p<0.01).

DISCUSSION

In this study, we describe a VR system that was developed for the assessment of cognitive ability in schizophrenia, based on the brain multimodal integration model. The VR 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 subject interpret 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

TABLE 5. THE CORRELATIONS BETWEEN VR INDEXES AND WCST INDEXES

		WCST Indexes		
		Perseveration	*Rule finding*	*Total*
VR Index	Perseveration	−0.585[b]	−0.108	0.157
(WOD)	Rule finding	−0.505[a]	−0.327	−0.453[a]
	Total Index	−0.636[b]	−0.151	−0.373
VR Index	Perseveration	0.585[b]	0.034	0.264
(WD)	Rule finding	−0.438[a]	−0.653[b]	−0.672[b]
	Total Index	−0.607[b]	−0.396	−0.547[a]

[a]Correlation is significant at the 0.05 level (2-tailed).
[b]Correlation is significant at the 0.01 level (2-tailed).

TABLE 6. THE CORRELATIONS BETWEEN VR INDEXES AND SPM SCORE

VR Indexes		*SPM*
Without distractors	Rule finding index	0.403*
	Perseveration index	−0.335
	Total index	0.441*
With distractors	Rule finding index	0.314
	Perseveration index	−0.393*
	Total index	0.415*

*$p < 0.05$.

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.

There are other advantages: VR could show how the 3D distractors could influence the human's cognitive ability. In addition, it could provide information about how the schizophrenic patient's perseverance behavior characteristic would be represented in 3D environment. Thus the VR could provide a patient with various stimuli in an immersive environment and allow the assessment of cog-

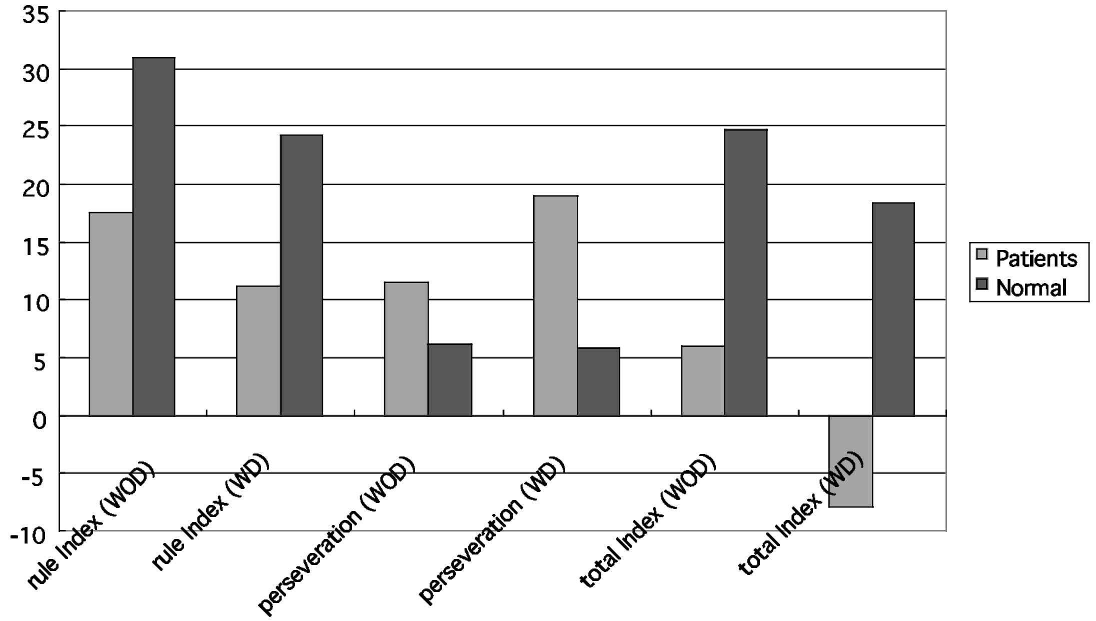

FIG. 3. Comparison between WOD and WD in each index.

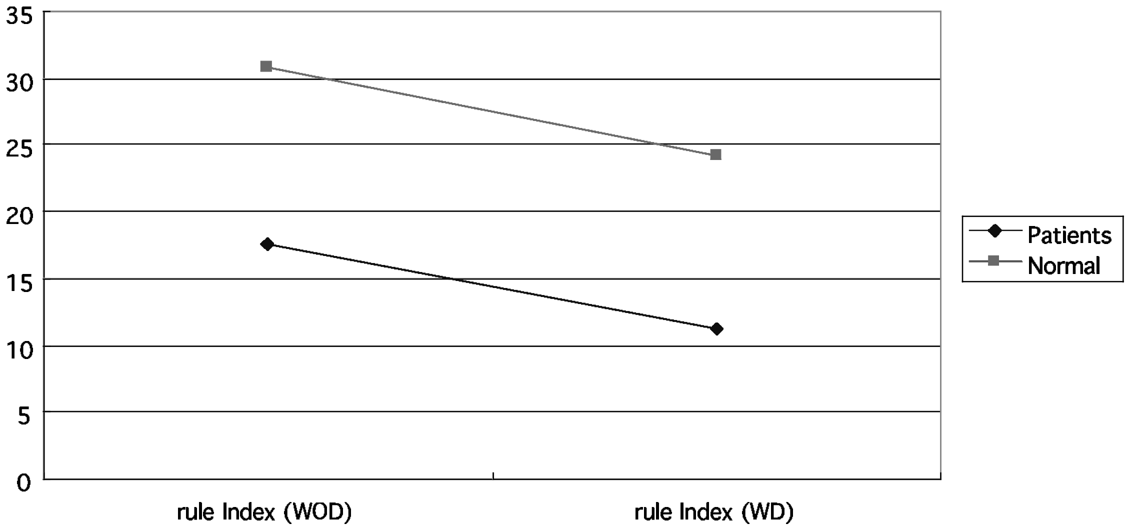

FIG. 4. Comparison of rule finding index between WOD and WD in both groups.

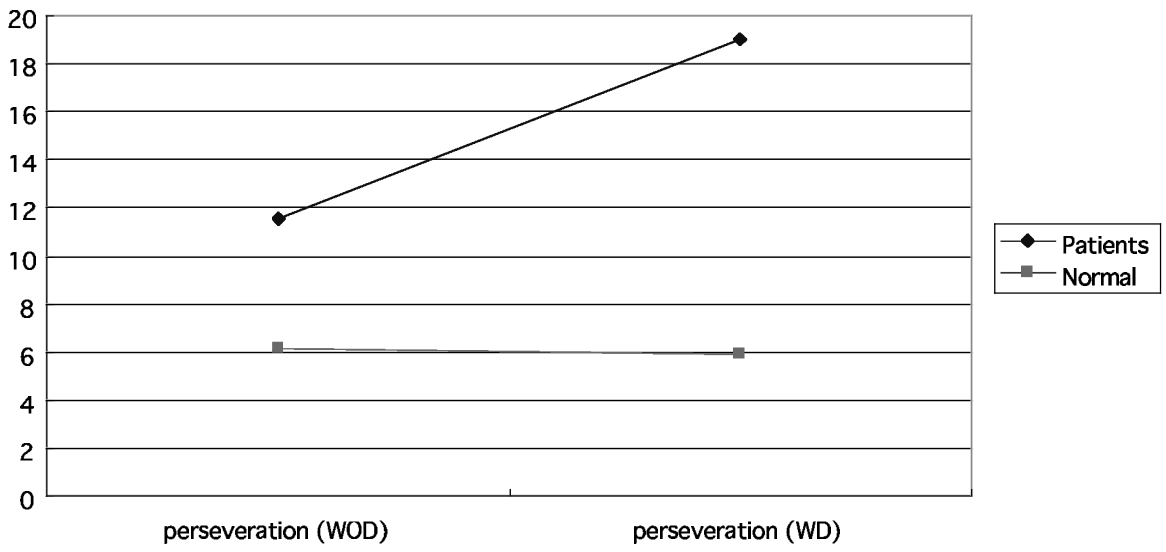

FIG. 5. Comparison of perseveration index between WOD and WD in both groups.

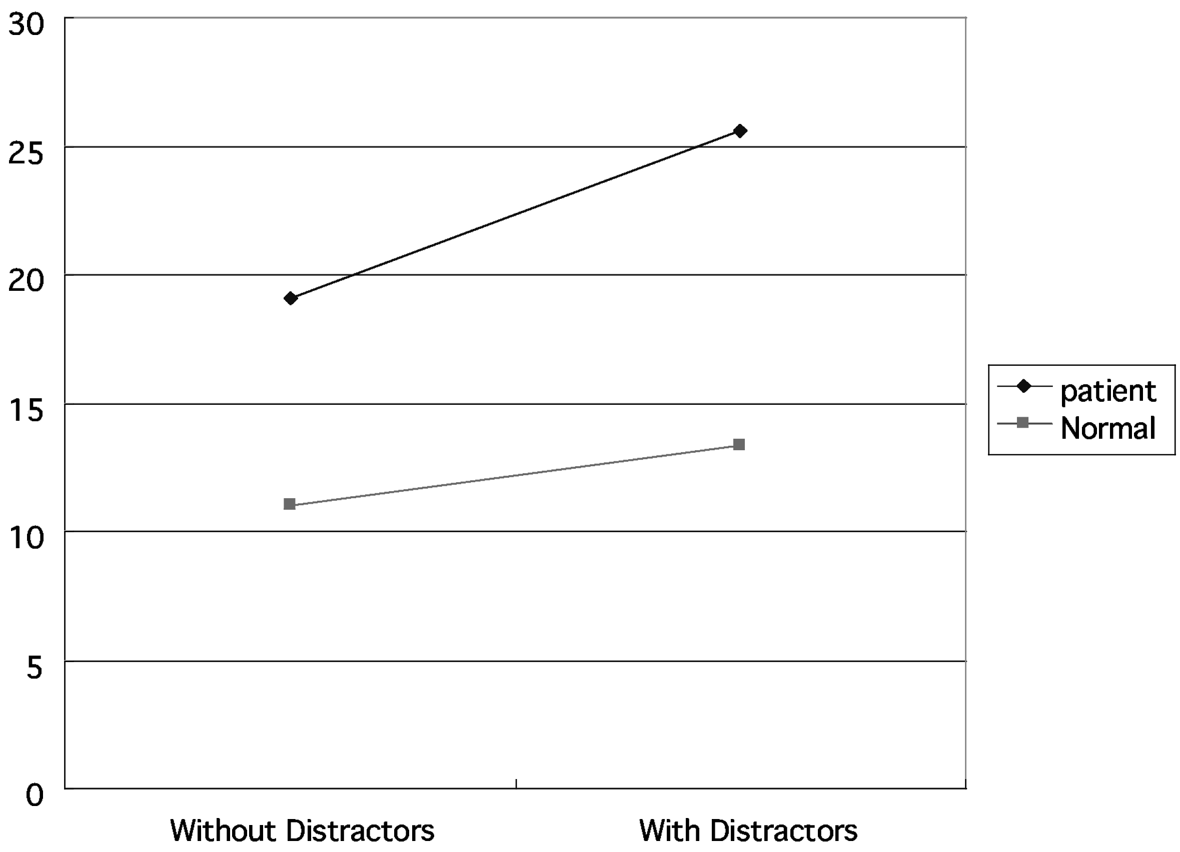

FIG. 6. Comparison of navigation index between WOD and WD in both groups.

nitive ability, and the identification of the relationships between cognitive functions.

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