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Unilateral spatial neglect affected by right-sided stimuli in a three-dimensional virtual environment: A preliminary proof-of-concept study

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***Abstract*—Unilateral spatial neglect (USN) is defined as the inability to attend and see on one side, which seriously interferes with daily life. Clinically, patients with left USN commonly demonstrate a striking immediate capture of attention from ipsilesional, right-sided items as soon as a visual scene unfolds (i.e., magnetic attraction [MA]). Therefore, this preliminary study utilized a three-dimensional (3D) virtual environment to evaluate the effects of eliminating stimuli in the rightward space and directing attention to the left on neglect symptoms. Methods: Seven patients with USN participated in this study, and two types of visual stimuli were created: the numbers and objects in the 3D virtual environment. To eliminate the visual stimuli on the right side, a moving slit was introduced in the virtual environment. During the experiment, patients were required to orally identify each object and number both in moving and nonmoving slit conditions. Results: A statistical comparison of scores with and without the moving slit in the 3D virtual space indicated significant changes in the object stimuli condition; however, no statistically significant difference was observed in the number stimuli condition. Conclusions: Masking the right side within the 3D virtual space increased the number of objects that can be recognized on the left side by patients with USN. The results may allow interventions in a virtual reality environment that closely resembles the patient's real-life space.**

***Clinical Relevance*—Magnetic attraction is a symptom seen in patients in clinical practice, but there is no method of rehabilitation. The proposed moving slit method is expected to be effective because it enables attention guidance in a three-dimensional space.**

Index Terms: Higher brain dysfunction, Unilateral spacial neglect, Immersive VR technology

I. Introduction

Unilateral spatial neglect (USN) is defined as a failure to report, respond, or orient to novel or significant stimuli presented to the side contralateral to a brain lesion, and is one of the most prevalent causes of brain dysfunction [1]. Clinically, patients with left neglect often demonstrate a striking immediate capture of attention from ipsilesional, right-sided items immediately after a visual scene unfolds (i.e., magnetic attraction [MA]) [2]. This symptom is thought to be caused by the inability to release attention from the right side and is observed in some patients with chronic and acute USN. Although anatomical study has not revealed clear lesion sites related to MA, the inferior front–occipital fasciculus disconnection could contribute to MA by impairing the top-down modulation of right-sided visual areas from the frontal cortex [3].

Mark et al. used a line cancellation task to demonstrate that USN is improved by removing the line with an eraser [4]; they concluded that USN is influenced by the presence of stimuli in the nonneglected hemispace. Although eliminating stimuli in the rightward space during the intervention may have contributed to the USN rehabilitation, a previous study using a paper test to eliminate objects on the right side in a 3D space similar to real-life space did not reveal the same impact. If a similar response can be obtained within the 3D environment, it could present a potential application as a new intervention technique for patients with USN. To assess this possibility, we experimentally tested the effects of eliminating the stimulus in the rightward space and directing attention to the neglected side in a 3D virtual environment using an immersive virtual reality (VR) system. This study hypothesized that eliminating the stimuli on the right side in the 3D virtual environment would reduce neglect symptoms.

II. Materials and Methods

A. Participants

Participants who had experienced a clinical ischemic or hemorrhagic cerebral vascular incident and presented to the

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rehabilitation departments in Kameda Rehabilitation Hospital were recruited. Patients who were admitted within six months of the stroke onset, were 45–85 years of age, had right hemisphere damage, and who scored below the cutoff value (i.e., 34) in the line cancellation test met the inclusion criteria for the study. Those who were unable to sit in a wheelchair or chair, were unable to endure the procedure due to cognitive impairment, experiencing hearing loss, having impaired eyesight (i.e., visual field deficit); or who refused to participate were excluded from the study. Ethical approval was granted by the Ethics Committee of Waseda University (approval number: 2015-251). This study was registered as a clinical trial with the University hospital Medical Information Network (UMIN) Center (ID: UMIN20114).

B. Virtual Reality System and Study Protocol

Our system consists of a head mounted display (HMD; Oculus Rift Development Kit 2, Oculus VR Inc., Irvine, CA, USA) and a personal computer (Fig. 1). The software was developed using Unity (Unity 5, Unity Technologies, San Francisco, CA, USA). A VR room was established (Fig. 2). Then, a visual searching task was created in the VR space. Two types of visual stimuli were prepared: numbers and objects (Fig. 2, 3). To eliminate the visual stimuli on the right side, a moving slit was developed in the virtual environment. The moving slit erased visual stimuli on the right side by slowly moving to the left side (Fig. 4). During this experiment, patients were required to orally identify each object and number both in the moving and nonmoving slit conditions. Responses to the number of objects and stimuli were each measured twice. The slit and no-slit conditions were administered in a random order among all participants.

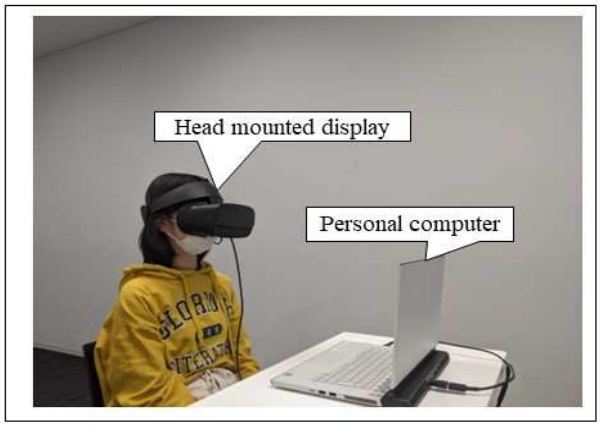

Figure 1. Overview of the VR system.

A VR space room (20 × 20 × 8 m) was set up, in which a desk was placed in the VR space. This system tracks head movements through an HMD sensor. Therefore, patient movements are reflected in the VR space. (Written informed consent was obtained from the depicted individual for the publication of this image).

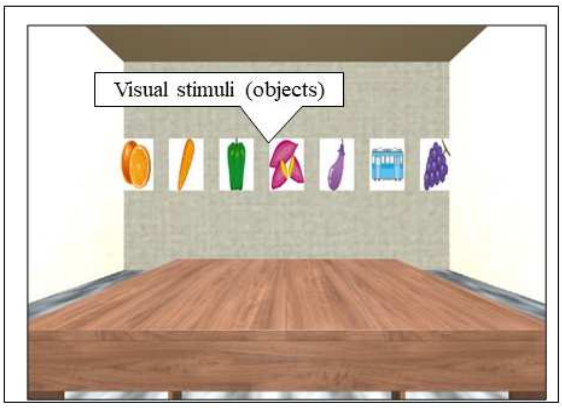

Figure 2. Snapshot virtual environment displayed to the user.

Visual stimuli of objects in the virtual environment

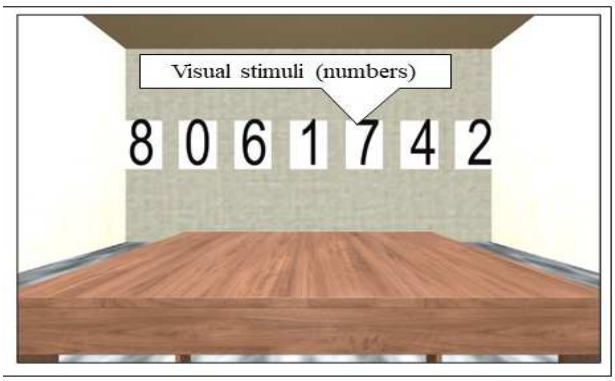

Figure 3. Visual stimuli of numbers in the virtual environment.

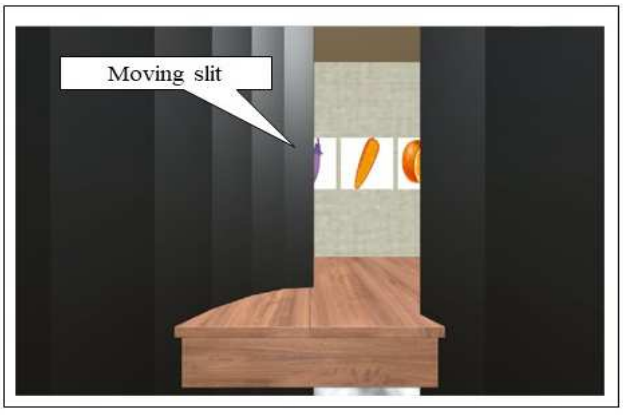

Figure 4. Moving slit in the virtual environment.

To draw attention to the left side in the VR environment, a moving slit was included by slowly drawing the projected image seen by the patient toward the left side. The test participant-centered slit moved 155° over time (the perceivable angle of the moving slit was fixed at 45°, and the moving speed was 2.58°/s; moving 155° in 1 min).

TABLE 1 DEMOGRAPHIC DATA OF PARTICIPANTS

Participant	Gender	Age	Stroke type	Days since stroke	Lesion side	Visual defect	MMSE*	Line cancellation
A	M	66	Hemorrhagic	47	R	(-)	20	18/36
B	M	47	Hemorrhagic	101	R	(-)	23	6/36
C	M	51	Hemorrhagic	93	R	(-)	27	18/36
D	F	72	Hemorrhagic	41	R	(-)	18	22/36
E	F	77	Infarcted	81	R	(-)	18	1/36
F	M	84	infarcted	158	R	(-)	20	11/36
G	F	81	Hemorrhagic	25	R	(-)	22	18/36

*MMSE: mini-mental state examination

TABLE Ⅱ The number of visual stimuli recognized by each patient (data from two measurements)

	Objects		Numbers	
Participant	Nonmoving slit	Moving slit	Nonmoving slit	Moving slit
A	3,2	7,7	4,4	7,7
B	0,1	0,6	0,2	4,4
C	2,3	4,5	7,7	6,7
D	5,7	7,7	2,7	3,6
E	0,0	0,0	0,0	0,0
F	3,5	5,7	7,7	5,5
G	7,6	7,7	4,4	5,7

C. *Data Acquisition and Analysis*

We recorded the number of responses for the number and object stimuli. To compare the effects of the moving and nonmoving slits in the object and number conditions, each condition was compared using Wilcoxon's signed-rank test [5] using GraphPad Prism (version 6.0, GraphPad Software, Inc.).

III. RESULTS

The demographic characteristics of participants are shown in Table 1. Data for each test are shown in Table 2. A statistical comparison of the total scores in the moving and nonmoving slits indicated significant changes in the object stimuli ($p = 0.0066$, $z = 2.71$); The number of recognizable objects increased with the slit. However, no statistically significant difference was observed in the number of stimuli ($p = 0.1512$, $z = 1.43$).

IV. DISCUSSION

In the present study, when visual information in the rightward space was deleted in the VR environment, neglect symptoms were reduced in the object stimulus condition. This result is consistent with that of the paper-and-pencil test reported by Mark et al. [4]. Since the VR-based manipulation used in this study closely resembles the daily living space, it may be adapted to patients with USN in the future.

The mechanism underlying the present results is unclear; however, the elimination of the rightward space may enhance passive attention on the neglected side [6]. Regarding the difference in results between the object and number stimuli, the relatively low-level regions from V1 to V4 process basic visual features, such as color, line segments, and motion, whereas higher-level regions closer to the temporal lobe process more complex individual objects, such as faces and objects that combine basic features [7]. Thus, the type of stimuli should be carefully considered when using the proposed VR system. Furthermore, the moving slit had no effect in patients with severe USN (i.e., patient E). Therefore, the severity of the USN may have to be considered prior to the application of this therapy in patients.

This research has clinical value because it demonstrates the potential to control the visual environment using immersive VR, as it is not possible to erase right-sided stimuli in living spaces. Rehabilitation of patients with USN, especially those whose attention is drawn to the right side, is particularly difficult. Thus, VR may offer new options for doctors and therapists.

This study is a proof-of-concept study; therefore, there are several experimental limitations due to its application as a feasibility study, namely, the small sample size, the individual differences participants' ages, and the extent of their symptoms. We understand that this study does not guarantee clinical effectiveness. Therefore, the clinical effects of eliminating stimuli in the rightward space with an immersive VR system must be assessed using a more rigorous study design.

V. CONCLUSIONS

In conclusion, this study evaluated the effects of eliminating object stimuli on the right side of a 3D virtual environment. As a result, neglect symptoms were reduced after eliminating the object stimulus on the right side. The results may allow further interventions for patients with USN in a VR environment that mimics their real-life conditions.

AUTHORS CONTRIBUTION

Kazuhiro Yasuda and Saki Takazawa contributed equally to this paper.

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INSTITUTIONAL REVIEW BOARD STATEMENT

The study was conducted according to the guidelines of the Declaration of Helsinki and was approved by the local ethics committee of Waseda University.

INFORMED CONSENT STATEMENT

Written informed consent was obtained from all individuals involved in the study. Data are available from the corresponding author on request. The data are not publicly available due to data privacy regulations.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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