

## CASE REPORT

# Differing effects of an immersive virtual reality programme on unilateral spatial neglect on activities of daily living

Kazuhiro Yasuda,<sup>1</sup> Daisuke Muroi,<sup>2</sup> Mizuki Hirano,<sup>2</sup> Kenta Saichi,<sup>3</sup> Hiroyasu Iwata<sup>3</sup>

<sup>1</sup>Research Institute for Science and Engineering, Waseda University, Tokyo, Japan

<sup>2</sup>Department of Rehabilitation, Kameda Medical Center, Chiba, Japan

<sup>3</sup>Graduate School of Creative Science and Engineering, Waseda University, Tokyo, Japan

## Correspondence to

Dr Kazuhiro Yasuda,  
kazuhiro-yasuda@aoni.waseda.jp

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## SUMMARY

In clinical practice, therapists often encounter cases of unilateral spatial neglect (USN) observed in far and near space. In this case report, immersive virtual reality (VR) technology was adopted as a therapy tool in a patient with stroke with severe near and far space neglect. Neuropsychological tests in near and far space as well as the Catherine Bergego Scale (CBS), as an index of neglect in daily living, were measured preintervention and postintervention. Improvement of neuropsychological tests, particularly in far space, was clearly demonstrated postintervention. However, CBS score did not change postintervention. This may be because the patient unsuccessfully translated these visual search task skills used in far space to activities of daily living. Our findings suggest the potential use of immersive VR technology in patients with USN and highlight the VR programme's limited ability to fully recover a patient's disability in natural settings.

## BACKGROUND

Unilateral spatial neglect (USN) is defined as a failure to report, respond or orient to novel or meaningful stimuli presented to the side opposite the brain lesion.<sup>1</sup> USN is one of the most prevalent higher brain dysfunctions, occurring in approximately 50% of patients with stroke,<sup>2</sup> and 90% of patients with USN have right hemisphere brain damage (eg, inferior parietal lobe, superior temporal, frontal cortex, subcortical nuclei).<sup>3</sup> USN manifests as neglect of attention to one-sided vision and localisation ability and interferes strongly in daily life. For example, individuals with USN leave food on the neglected side of their plate and fail to look to the neglected side when crossing the street.

In recent years, USN intervention techniques that use various types of virtual reality (VR) have been proposed (eg, street crossing, visual search task, active upper body activities, wheelchair navigation/obstacle avoidance course tasks). A 2015 review<sup>4</sup> reported that although VR is an effective tool for the treatment of USN, most existing VR interventions have employed non-immersive VR. For example, three fair-quality RCTs,<sup>5,6</sup> one quasiexperimental study,<sup>7</sup> one case study<sup>8</sup> and one case-series study<sup>9</sup> investigated the effects of non-immersive VR on USN in patients with stroke. Because immersive virtual reality provides first-person perspective practice through the use of a head-mounted

display (HMD), we can speculate that these components may strongly influence users' sense of control, multimodal interaction, immersion in first-person view or visual feedback. To make the most of the advantages of the immersive VR system, we developed a first-person view in an immersive VR environment with an HMD to develop a tractable rehabilitation system that allows training in three-dimensional (3D) virtual environments in both near and far space.<sup>10</sup>

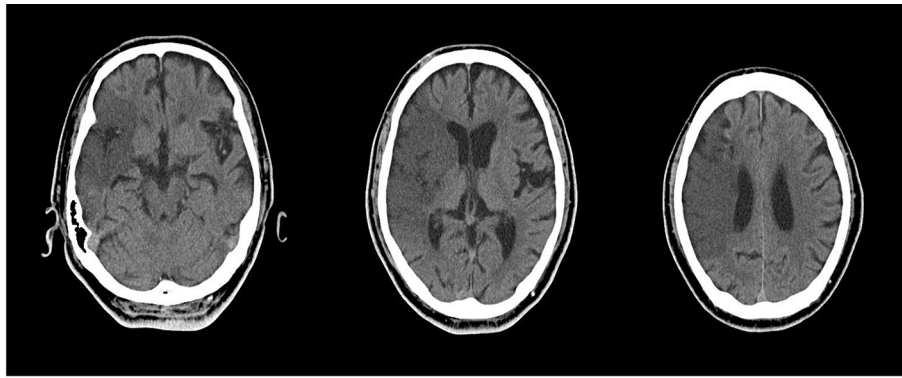
In actual clinical practice, therapists often encounter cases of visual neglect observed in both far and near space, as well as far or near space only.<sup>11</sup> The immersive VR system seems to represent a promising tool for USN treatment in both far and near space; however, our previous work only showed that training during a single session of an immersive VR programme led to immediate improvement in far space line cancellation tasks.<sup>10</sup> Thus, the effects of long-term therapy and neglect in daily life, which are very important elements of USN rehabilitation, remain unknown. The purpose of this case study was to assess whether 6 weeks of a daily immersive VR programme could induce improvement and behavioural change in daily life in a case with severe spatial neglect.

## CASE PRESENTATION

A male patient, aged 76 years, suffered a right middle cerebral artery (MCA) infarct (figure 1). He had no history of neurological or psychiatric disorders. His medical history was significant for diabetes, cholecystitis and an inguinal hernia. He was independent in everyday life (Barthel index score 100), and he worked in a fish shop. Lesions on the frontal, temporal and parietal lobes of the right hemisphere were observed in MRI and CT examination. The patient did not have a visual field defect, anosognosia and sensory or visual inattention (ie, extinction phenomenon). He experienced severe left hemiparesis and required assistance for all activities of daily living (Barthel index score 0). The presence of left spatial neglect, which affected his sitting balance and posture, was notable throughout the administration of the National Institutes of Health Stroke Scale. At 2 weeks (15 days) after onset, he scored 20/30 (normative cut-off, 24/30) on the Mini-Mental State Examination (MMSE), primarily indicating memory decline. He still scored 0 on the Barthel index of daily life activities. He always rotated his neck to the right and often failed to respond when



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**Figure 1** CT scans (1 day after onset). Three slices (3 cm interval). Extensive cerebral infarction in the middle cerebral artery area due to occlusion from the right internal carotid artery. Old cerebral infarct exists in right and left basal ganglia. In addition, there is contraction in both hippocampi.

addressed from the left during daily life. When completing the line cancellation test, he was only able to delete one row from the right; furthermore, he repeated that cancellation on the same line. At 7 weeks (50 days) after onset, he was transferred to the rehabilitation hospital. His MMSE score (25/30) exceeded the cut-off at 58 days after onset. His Barthel index score rose to 15. At the time of study enrolment, 72 days after onset, he had moderate paralysis on the left side of his body and required moderate assistance (Barthel index score 25). We conducted the line cancellation test in both near (table test) and far (projector) space and observed severe impairment in performance, especially in far space (scores: far space, 6/36 lines; near space, 15/36 lines).

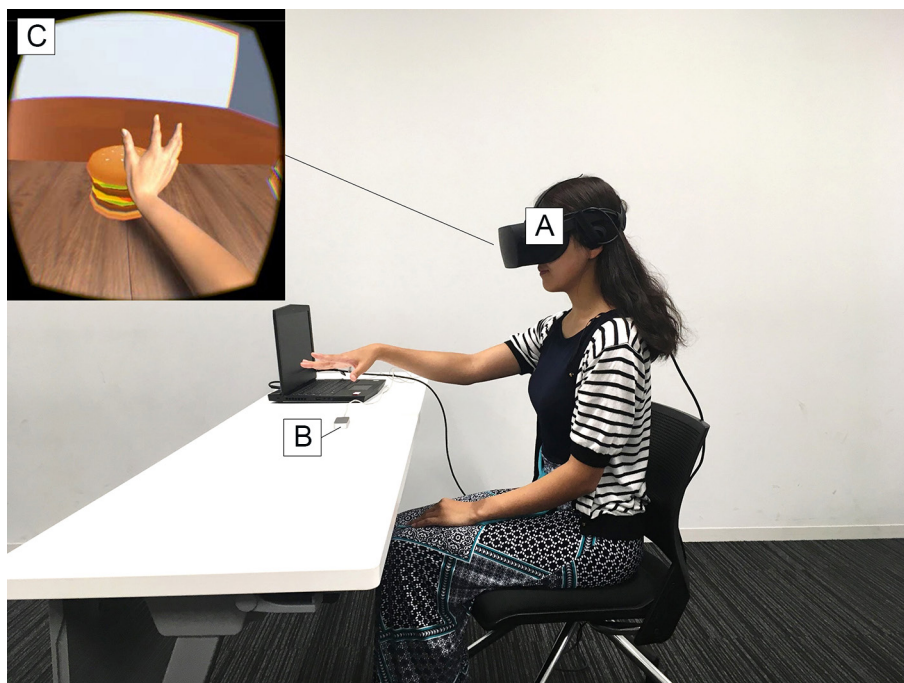
## TREATMENT

### Immersive VR programme

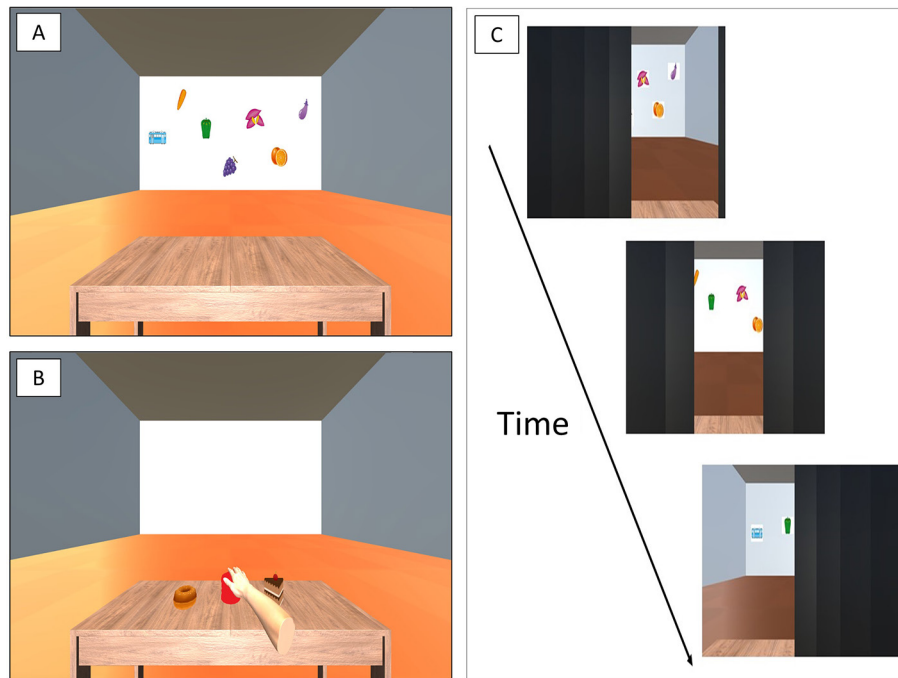
Our VR system consists of an HMD (Oculus Rift Development Kit 2, Oculus VR, Irvine, California, USA), a motion-tracking device (Leap Motion, Leap Motion, San Francisco, California, USA) and a personal computer. The system tracks head and

finger movements through the HMD sensor and motion tracker (figure 2). Therefore, the patient's hand and head movements are reflected in the VR space.

During the immersive VR programme, the patient sat in a wheelchair, and two types of training sessions were performed continuously for approximately 10 min each, with an interval between them. For the far space training, the patient performed a visual search task in the VR space. During the session, the task required the patient to orally identify each flashing object (figure 3A). During the near space training, the patient performed a reach task in the VR space. During this session, the patient was required to extend his hand in VR to touch each object in order from right to left (figure 3B). To effectively perform both training sessions, we included a moving slit in the virtual environment (figure 3C). It is generally understood that hemispatial neglect is influenced by the presence of stimuli on the non-neglected side.<sup>12</sup> Mark *et al* found that during line cancellation tests, performance on the visual search task is improved when the stimulus is removed from the non-visual neglected side.<sup>12</sup>



**Figure 2** Overview of the virtual reality system. (A) Head-mounted display; (B) motion tracker and (C) snapshot virtual environment being displayed to the user.



**Figure 3** Immersive VR programme. A VR space room (20 m×20 m×8 m) was set up for both near and far space training, in which a desk was placed in the VR space. (A) For far space training, a virtual screen was located 15 m from the patient and seven visual stimuli were placed on the screen. Visual stimuli flashed consecutively for 6 s each from the right to the left side of the screen. (B) For near space training, three objects were placed on the table in the VR space. The patient was able to move the VR hand by moving his own hand; when the VR hand touched the object, the object turned red. (C) To draw attention to the left side in the VR environment, we included a moving slit and slowly drew the projected image seen by the patient towards the left (the slit was added as per the far and near figures shown above). The test participant-centred 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. VR, virtual reality.

Based on these findings, we introduced a moving slit to the virtual environment to promote attention disengagement and shifting of attention to the neglected side, shutting down the stimulus on the non-neglected side.

### Procedure

The patient performed the VR programme as an inpatient programme. The intervention lasted approximately 30 min per session, once a day, five times a week, over a period of 6 weeks. We assessed the patient's neglect symptoms preintervention and postintervention. To assess the impact of the VR programme, baseline data were obtained 6 weeks preintervention. Ethical approval was granted by the Ethics Committee of Waseda University (approval number: 2015–251).

### OUTCOME AND FOLLOW-UP

#### Outcome measures

Regarding the current case, we were especially interested in testing neuropsychological tests in both near and far space as well as assessing neglect symptoms in daily life. Thus, primary outcome measures were as follows.

- Line cancellation test: line cancellation is a modified form of Albert's test, in which the patient is asked to cross out a number of lines on a page. The A4 sheet contained 40 targets (a total of 36 columns, excluding the four central columns) and was placed on the patient's midline.
- Line bisection test: in this task, the patient was asked to mark the centre of three horizontal lines (20 cm) that were respectively placed on the right, centre and left of an A4 sheet. Deviation from the true centre was measured in mm (ie, rightward deviations indicated positive signs). Deviations

(in mm) from the three lines were divided by the correct length (20 cm). This quotient was multiplied by 100, yielding a percentage deviation, with a marked rightward deviation representing a high positive score.

- The Catherine Bergego Scale (CBS): the CBS is based on direct observation of the patient's functioning in real-life situations. The CBS includes 10 items that correspond to common, everyday life situations (eg, hair care, shaving, putting arms through sleeves, facing the left, etc). Each item was assessed on a 4-point scale ranging from 0 (no neglect) to 3 (severe neglect) and the total score was calculated (range 0–30).

Assessments (a) and (b) were conducted to ascertain the presence of neglect in both near and far space.<sup>13</sup> In the near space assessment, stimuli were presented in front of the patient on an A4 sheet placed horizontally at a distance of 40 cm from the patient's eyes. Far space performance was evaluated by projecting the tests on the wall with an overhead projector, at a 240 cm distance between the midline of the patient's body and the display. The length and the width of the test battery were corrected to identical angular sizes of stimuli in near and far space (ie, visual angle of each test was kept constant during both conditions).<sup>13</sup> For assessments of both near and far space, the patient performed the tasks with his right hand, using a pen in near space and a laser pointer in far space.

#### Follow-up examination

There were no side effects related to 3D visual stimuli (ie, motion sickness, dizziness or vertigo) during the immersive VR programme/intervention period.

**Table 1** Scores on the CBS and primary neuropsychological measures in near and far space, pre-VR and post-VR programme

	(Near) Line cancellation; (omission rate)	(Far) Line cancellation (omission rate)	(Near) Line bisection	(Far) Line bisection	CBS
Baseline (6W before)	15 (58%)	6 (83%)	74	86	14
Pre-VR	6 (83%)	6 (83%)	86	87	15
Post-VR	23 (36%)	29 (19%)	72	76	15

Neglect symptoms were measured every 6 weeks for a total of three times: at baseline (6 weeks pre-VR programme), as well as preintervention and postintervention. CBS, Catherine Bergego Scale; VR, virtual reality

A follow-up examination was performed preintervention and postintervention (immersive VR programme) to compare the outcomes with those from the baseline measurement taken 6 weeks prior to intervention. Changes in the primary outcome measures are shown in table 1. The patient showed improvement in the omission rate in the line cancellation test in far space and near space. In the line bisection test, the patient showed a shift in the midpoint in near space and far space, demonstrating improvement. In contrast, no improvement was observed on the CBS (ie, patient’s score did not change preintervention vs postintervention).

**DISCUSSION**

In this case report, we report the case of an older adult male patient who suffered from severe USN in near and far space caused by a right MCA infarct. Using the immersive VR programme, his performance on typical neuropsychological tests showed marked improvement, especially in the line cancellation test in far space. However, no changes were observed in the patient’s score on the CBS, which assesses symptoms of neglect in activities of daily living. This case study is the first to report beneficial effects of the use of a 6-week immersive VR programme and differing effects of the VR programme on outcomes of neuropsychological test versus the CBS (ie, neglect in activities of daily living).

In clinical settings, cases of visual neglect have been observed in both far and near space, as well as far or near space only<sup>11</sup>; thus, it is important to provide effective intervention for near and far space neglect. Our case had extensive cerebral infarction in the MCA area due to occlusion from the right internal carotid artery, leading to severe neglect, especially in far space. Despite his severe condition, compared with baseline, he showed marked improvement on neuropsychological tests administered preintervention and postintervention (6-week period). These results replicated our previous findings which indicated that the immersive VR programme is advantageous for performing visual search tasks, especially in cases of far space neglect.<sup>10</sup> Thus, the immersive VR programme is likely to have beneficial effects which are similar to interventions using visual search tasks in real environments.<sup>14</sup> The same effects may also be anticipated in immersive VR environments using HMDs. As the HMD system does not require a large-scale display in real environments, it could have use for tasks that can be performed at the patient’s bedside or at home.

Regardless of the fact that the programme was shown to be effective in typical neuropsychological tests, there was no change in the patient’s CBS score throughout the intervention period. Although the reason for this is unclear, we know that the CBS focuses primarily on assessment of activities performed in the patient’s immediate physical vicinity (eg, hair care, shaving, putting arms through sleeves, facing left, etc). It is thus plausible that the patient unsuccessfully translated these visual search task skills used in far space to activities of daily living. Other

possibilities are that CBS may not sensitive enough to detect the potential effect of VR in activities of daily living, or the effect would be found in the follow-up phase. Further, the evaluation with CBS would differ depending on the age of the patient. Hier *et al* reported that patients younger than 60 years recovered more quickly from USN.<sup>15</sup> Given that the case was an older adult patient, the patient unsuccessfully translated the effect of VR to activities of daily living.

As a cautionary note, we cannot discount the effects of natural recovery and placebo when considering the patient’s improvement. However, given that the patient showed relatively stable neglect in the 6-week baseline period prior to intervention, we believe that his sudden improvement on neuropsychological tests at follow-up truly reflect the beneficial effects of the immersive VR intervention. Further, CBS would have been different depending on the age of the patient. Thus, we cannot exclude potential bias from this effect.

In summary, a 6-week intervention using an immersive VR system improved performance on neuropsychological tests in a patient with severe USN. The immersive VR system may therefore make a valuable contribution to novel interventions delivered in clinical settings that address specific types of neglect. However, we acknowledge that it may not necessarily be appropriate to generalise these beneficial effects to neglect symptoms in daily life.

**Learning points**

- ▶ In clinical settings, unilateral spatial neglect (USN) has been observed in both far and near space, as well as in far or near space only; thus, it is important to provide effective intervention for near and far space neglect.
- ▶ We observed a patient who suffered from severe USN in both near and far space caused by a right middle cerebral artery infarct and conducted a 6-week novel immersive virtual reality (VR) intervention using a head-mounted display.
- ▶ Use of the immersive VR programme was associated with improved performance on neuropsychological tests in a patient with severe USN; however, assessment in daily life revealed no improvement after the intervention.
- ▶ The use of an immersive VR programme represents a promising tool for neglect rehabilitation; however, therapists should note that these beneficial effects may not necessarily transfer to daily life.

**Contributors** KY performed the design of this study, acquisition and analysis of data and drafting the manuscript. DM, MH and KS made substantial contributions to the acquisition and analysis of the data. HI was involved in the conception of the system and design of the study. Each of the authors has read and concurs with the content of the final manuscript. No one who qualifies for authorship has been omitted from the list.

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**Patient consent** Obtained.

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