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Visual function assessment in stroke patients using a dynamic three-dimensional visual tasks

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Abstract

Objectives: Patients with right-hemisphere brain lesions often show unilateral neglect, which causes various difficulties in their daily lives. Disturbances in visuospatial cognition, including unilateral neglect, can be tested quantitatively using questionnaires, yet visuospatial cognition is related not only to the visual system, but also to other cognitive and behavioral functions. Such functions should be assessed by integrative visuo-cognitive tasks. Therefore, the objective of the present study was to clarify visual disturbances in patients with brain lesions using multi-modal visual function tests including three-dimensional and dynamic visual tasks.

Methods: We recruited 29 patients, 14 with right- and 15 with left-hemispheric brain lesions, and age-matched control subjects. We conducted depth perception tests and static and active motion detection tests to clarify subjects' three-dimensional visual recognition performance.

Results: There were no significant differences between the patients and controls on any of the visual function tests, except for the static detection test with a mosaic background. However, patients' total scores on the visual function tests were lower than those of the controls.

Discussion: The observed decline in total visual function scores suggests that visual dysfunction caused by stroke should be evaluated not by a single visual function test, but by a series of such tests. We propose that visual functioning in daily life should be evaluated using multi-modal visual function tests.

Keywords: Depth perception, Vision test, Visual function, Unilateral neglect, Evaluation

Introduction

Patients with brain lesions often show disturbances in visuospatial function, including unilateral neglect (ULN), which may affect many activities of daily living. For example, in stroke patients, ULN is common in the acute and recovery phases, up to 3 months after onset,[1] and approximately 60% of a stroke rehabilitation patient population was reported to have ULN.[2] Visuospatial functioning can be clinically tested in various ways, but clinicians do not agree on the most effective method.[3,4] One problem with assessing disturbances in visuospatial function is that bedside examinations or test batteries using paper-and-pencil tasks do not always reveal the problems experienced in daily life.[5] Visuospatial dysfunction based on behavior and problems with activities of daily living should be assessed in rehabilitation units, but the number of reports is limited.[6,7]

Disturbances in visuospatial cognition, including ULN, are conventionally assessed by desktop tests such as line dissection and drawing symmetric items.[8] These criterion measures are well-established tasks, and unilaterally impaired performance suggests underlying ULN.[9] However, they are static cognitive tests on a single plane, yet disturbances caused by visuospatial dysfunction are sometimes worse when performing voluntary actions involving surrounding objects.[10] Visuospatial functioning depends not only on the visual system, but also on other cognitive and behavioral functions such as cognitive awareness of the spatial frame and body centered images.[10–12] In the field of rehabilitation, it is important to comprehensively evaluate visual functioning, which might affect patients' activities of daily living.

Therefore, we consider it important to evaluate visual functioning using multi-modal visual function tests, including three-dimensional and dynamic visual tests. In the present study, patients with visual function disturbance after stroke were assessed using three-dimensional and moving visual tasks. Total scores obtained from the tests were compared to assess patients' behavior and problems in daily life.

Methods

Participants

Twenty-nine patients (19 males and 10 females, mean age: 59.8±13.3 (SD) years) with mild to moderate hemiparesis and visuospatial function disturbances, including ULN, participated in the study. The locations of brain lesions and the clinical profiles of the patients varied, as shown in Table 1. Twenty-six age-matched healthy controls (15 males and 11 females, 57.7±13.8) also participated in the study. The healthy controls had no history of neurological disease, and no neurological symptoms at the time of the study.

This study was approved by the Ethical Committee of Fujita Health University (No. 17–25), and written informed consent was

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Table 1 Profile of the patients

No.	Side affected	Age	Sex	Lesion*	Period after onset	Visual field loss	Brunnstrom's Recovery Stage in arm
1	R	45	M	I	1Y2M	none	V
2	R	61	F	H	2Y11M	none	II
3	R	61	M	H	6Y6M	none	III
4	L	81	M	I	6M	none	IV
5	R	64	M	H	7M	none	IV
6	R	70	M	I	2Y9M	none	III
7	L	77	M	I	6M	none	V
8	R	31	F	I	8M	none	II
9	R	61	M	I	1Y2M	R	III
10	L	56	M	I	8M	L	III
11	L	61	M	H	1Y2M	none	III
12	R	72	M	I	4Y9M	none	III
13	L	53	M	H	10M	none	III
14	L	60	F	H	3M	L	V
15	L	61	M	I	3M	L	V
16	R	70	F	I	3M	none	V
17	L	62	M	H	5Y2M	none	III
18	R	59	M	I	3M	none	VI
19	R	57	M	I	3M	none	V
20	L	23	M	I	2M	none	II
21	L	76	F	I	2M	none	IV
22	R	46	F	H	2M	none	I
23	R	59	M	H	5M	R	II
24	L	68	F	I	3Y	L	III
25	L	63	M	H	1M	none	V
26	L	64	F	I	4Y6M	none	III
27	L	36	F	H	6M	none	III
28	R	73	F	H	1M	none	V
29	R	65	M	I	1M	none	II

* I: cerebral infarction, H: intra-cerebral hemorrhage

obtained from all participants prior to the start of the study.

Experimental design

A series of visual perception tests was performed, including tests of depth perception and static and active motion detection, and all subjects were asked about their subjective sensation of visual disturbance while performing daily activities.

Depth perception tests

The subjects were seated on a chair and were asked not to move their heads. Depth perception in the antero-posterior and lateral directions was tested while seated. Reference and target points in the test were indicated by a yellow ball (3.7 cm in diameter) on an 80-cm-high pole.

For the antero-posterior depth perception test (Figure 1), two reference points, near and far, were placed 100 and 300 cm in front of the subject, respectively. A target point was presented to the subject at the midpoint between the near and far referential points. The subject was asked to state whether the target point needed to be moved so that it was located at the midpoint, and the examiner moved the target point accordingly. When the subject agreed that the target point was at the midpoint, the distance between the near reference point and the target point was measured. Two trials were conducted for each participant, and the mean distance was calculated.

For lateral depth perception (Figure 2), right- and left-side tests were applied. The right and left reference points were placed 50 cm apart on a line 300 cm in front of the subject. The midpoint between the right and left reference points was at the center of the subject's body. For the right-side test, a target point was initially placed 50 cm to the right of the right reference point, and the subject was asked to state whether the target point needed to be moved laterally toward the right reference point so

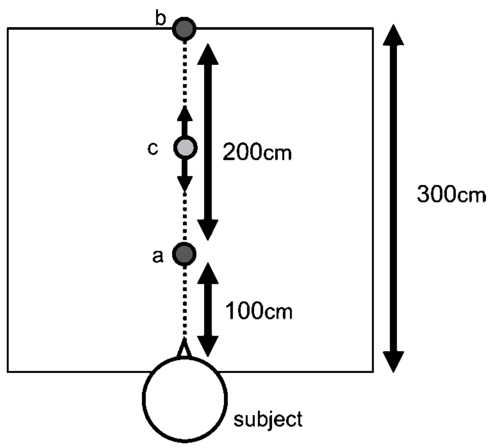

Figure 1 Experimental setting for the depth perception test: Antero-posterior direction. Subjects were asked to indicate the position of marker c (open circle) at the midpoint between markers a and b (gray circles).

that there was an equal distance between the right and left reference points. The distance between the target and the right reference point was measured. The same test was performed on the left side. Two trials were repeated for each participant on each side, and the mean distance was calculated. The order of the initial test side was decided randomly.

Static detection test

The subject was seated on a chair, as in the depth perception test, and instructed to gaze at a figure displayed on a screen monitor placed 100 cm in front (17 inches, diagonal). Six geometric figures were prepared for the test. Five figures were selected and presented in a random order on a black background for 0.16, 0.32, 0.48, 0.64, or 0.80 sec. The figures and presentation periods were randomly combined. Another five figures were selected from the same six figures, and they were presented on a black and white mosaic background (Figure 3). The presentation periods were similarly combined with the figures. Thus, five figures on a black background and five figures on a mosaic background, all with varying presentation periods, were prepared for each subject. The 10 figures were presented individually in random order in an 8×8-cm area (9.2 degrees, visual angle) of the screen for each subject. After presentation of each figure, a list of six figures, including a figure presented, was presented on the monitor. The subject was asked to select same figure as one presented and to answer it orally. When the subject correctly answered, a score was given depending on the presentation duration of the figure (Table 2).

Active motion detection test

After a short rest, the subjects completed an active motion test. The subject was seated on a chair, as in the depth perception test, and instructed to gaze at the center of a screen monitor placed 100 cm in front. At the center of the screen, a fixation point, “+”, was presented in the upper, lower, right, or left peripheral visual field. When the symbol was presented in one position and then another without an interval, it seemed to have moved, based on the effect of apparent motion.[13,14] A visual motion stimulus produced by apparent motion is identical to a stimulus induced by actual motion.[14] The symbol was moved in the range of 1 to 4 cm on the monitor screen in each trial, which corresponded to 0.57 to 2.29 degrees of the visual angle, respectively. Each subject performed 10 trials, and the subject was asked whether the symbol had moved after each trial or not. The subject was instructed to answer “moved” or “not moved” orally after each trial, and a score was given depending on the distance of the motion when the subject correctly answered (Table 3).

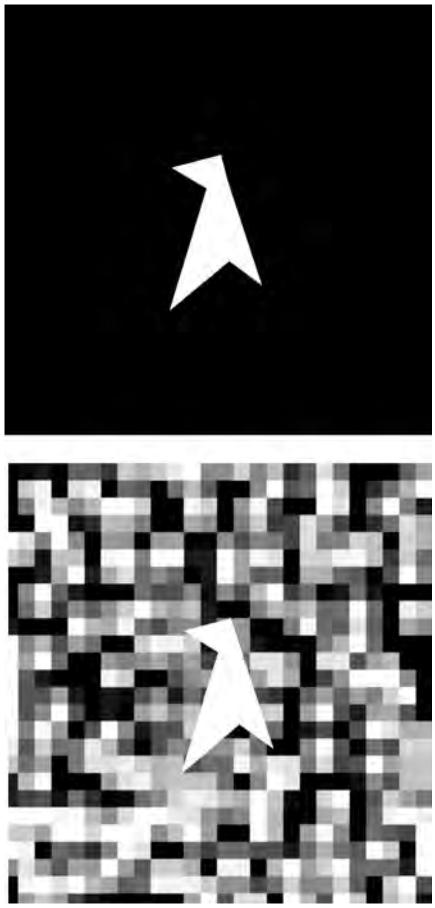

Figure 3 Geometric figures used for the static motion detection test. A black background (above) and mosaic background (below) were used.

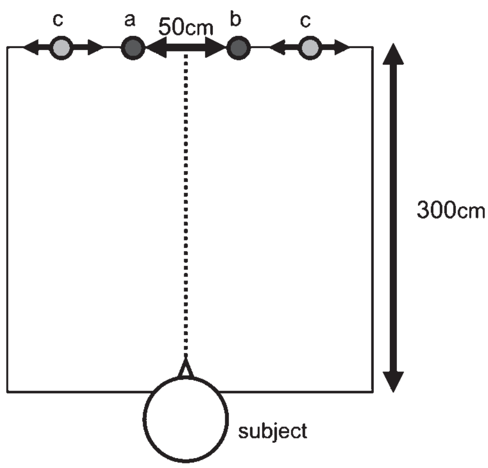

Figure 2 Experimental setting for the depth perception test: Lateral direction. Subjects indicated both marker-c positions when they were equidistant from marker-a (left) and -b (right).

Table 2 Scores on the static test

Duration (ms)	Score
16	5
32	4
48	3
64	2
80	1
80<	0*

* When the subject did not recognize the figure, the score was 0 .

Table 3 Scores on the active motion test

Distance (cm)	Score
4.0	1
3.0	2
2.0	3
1.0	4
0	−1*

* When the subject answered “moved,” the score was −1.

Visual function scores

The visual function score was determined and standardized for each test. For the depth and horizontal perception tests, each value in cm was divided by the standard deviation of the scores of the healthy subjects.

Scores for the static and active motion detection tests were determined by the distance and duration presented, as shown in Tables 2 and 3. The total scores for 5 and 10 trials were obtained in the static and active motion detection tests, respectively. These scores were standardized by dividing each value by the standard deviation of the scores of the healthy subjects. A visual function score, which was summation of standardized static and active motion scores, was finally obtained for each subject.

Subjective sensation of visual disturbance in daily activities

The subjects completed a questionnaire on the physical problems caused by their visual disturbances during daily activities. The questionnaires included items to measure problems inside and outside the house, in the community, and with transportation. The subjects also completed the Mini-Mental State Examination (MMSE).[15]

Statistical analysis

The total visual function scores of the patients and healthy subjects were compared. The correlation between total visual function scores and subjective sensation of visual disturbance scores was tested by non-parametric ANOVA and unpaired t-tests. The correlation between total visual function scores and MMSE scores was tested by the Mann-Whitney test.

Results

Depth perception tests

The depth perception test scores did not differ between the patient (96.1±5.4 (SD) cm) and control (95.8±3.6) groups. The scores also did not differ between patients with left- and right-sided brain lesions (left lesion, 96.7±5.5, right lesion, 95.6±5.3). Furthermore, in the horizontal depth perception test, there was no significant difference between the scores for patients (rightward, 49.2±1.6, leftward, 48.5±1.5) and controls (rightward, 49.7±2.6, leftward, 48.9±2.6). The scores did not differ between patients with left- and right-sided lesions (left brain lesion: rightward, 50.2±2.8, leftward, 49.6±2.9, right brain lesion: rightward, 49.2±2.5, leftward, 48.1±2.2).

Static detection test

For the stimulus with a black background, there was no significant difference in scores between the patients (27.1±3.0 (SD) points) and controls (28.5±2.4). For the stimulus with a mosaic background, patients scored significantly lower than the controls (patients 8.8±9.82, controls 25.2±4.5; t-test, $p<0.05$). There were no significant differences in the scores between patients with left- and right-sided brain lesions (left brain lesion, 18.3±11.3, right brain lesion, 19.2±9.4).

Active motion detection test

There was no significant difference in the mean test scores between patients and controls, as shown in Table 4.

Subjective sensation of visual disturbance in daily activities

There was no significant difference in the subjective sensation of visual disturbance between patients and controls.

Table 4 Scores on the active motion detection test

	controls	patients
Right field	25.0±1.9	22.1±6.6
Left field	24.4±2.8	22.6±6.7
Upper field	25.1±1.6	24.1±4.0
Lower field	24.9±0.3	24.3±2.4

Unpaired t test ($p>0.05$)

Total visual function scores

The mean total visual function score for the patient group (17.7±12.2 (SD) points) was significantly higher than that of the control group (9.6±3.8 points). Patients with left-sided brain lesions scored significantly higher (19.1±10.4 points) than those with right-sided brain lesions (16.6±10.7 points) ($p<0.05$).

MMSE

There was no significant difference in the total visual function score between the participants with low MMSE scores (16.0±9.7 points, 23 points or less, mean age: 59±3.6 years) and those with normal scores (18.2±10.7 points, 24 points or more, 60±16.3).

Discussion

The results of the present study can be summarized as follows: 1) there were no significant differences in patient and control scores for any of the visual function tests, except for the static detection task with a mosaic background; however, 2) patients' total visual function scores were lower than those of the controls. The results suggest that visual dysfunction caused by stroke should be evaluated not only by specific visual function tests, such as tests for ULN, but by a range of tests including dynamic and motion function tests. Because stroke causes lesions in diverse regions of the brain, and multiple lesions are not uncommon, a specific visual function test might not be sufficient to evaluate visual functioning related to daily activities.

Depth perception is an important visual function for performing daily activities. There was no significant difference in depth perception between the patients and controls in the present study. In a basic study, depth perception involved an outside of visual area, such as the caudal intraparietal. It means that the perception of depth depends not only on binocular disparity, but also on the width, texture, and velocity gradients (motion parallax).[16–18] The fact that multiple systems are involved in depth perception might help to preserve this function in patients with focal stroke.

The total visual function score provided an effective overview of patients' visual function. The visual function scores in the patients indicated lower visual function than in the controls, although none of the sub-tests for visual function revealed a difference between the groups. We contend that visual function actually involves multi-modal functions, such as the perception of contrast, motion, and depth, and that a combination of partial deficits in each modality might result in visual disturbances in daily life.

The static detection test with a mosaic background showed a significant difference in performance between patients and controls. Although we could not identify the pathophysiology from the present results, problems with figure-ground differentiation and impaired short-term memory have been shown to be related to the impaired performance on the static detection test in the patients.[19,20]

The aim of this study was to characterize the visual performance of patients with stroke by assessing their overall visual function, including three-dimensional, dynamic, and motion detection functions. These components of the visual system relate to spatial awareness in daily life. The present results suggest that it is insufficient to test visual functioning in stroke patients using only desktop tasks, because there are large inter-individual differences in brain lesions and the various components of the visual system could be partially damaged. Patients with stroke might not be aware of any visual disturbance in their daily lives, and visual tests may also fail to disclose such disturbance even when patients' visual function has declined overall. This is an important issue for the rehabilitation of patients with stroke.

Conclusion

In this study, we assessed visual functioning in patients with stroke using a range of tests, including dynamic and three-dimensional visual tests. Despite finding no specific visual dysfunction on individual tests, patients' total visual function scores showed a decline compared with the healthy controls. The characteristics of patients' visual function after stroke must be taken into account in their rehabilitation.

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Conflicts of Interest and Source of Funding:

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