

*Original Article***Aphasia testing (auditory comprehension domain) using a new eye-tracking system in healthy participants**Risa Sakai, MD,<sup>1,2</sup> Yasuharu Koike, D.Eng, PhD,<sup>3</sup> Kimio Saito, MD, PhD,<sup>4</sup>Toshiki Matsunaga, MD, PhD,<sup>4</sup> Yoichi Shimada, MD, PhD,<sup>5</sup> Naohisa Miyakoshi, MD, PhD<sup>1</sup><sup>1</sup>Department of Orthopedic Surgery, Akita University Graduate School of Medicine, Akita, Japan<sup>2</sup>Akita Prefectural Center for Rehabilitation and Psychiatric Medicine, Akita, Japan<sup>3</sup>Institute of Innovative Research, Tokyo Institute of Technology, Yokohama, Japan<sup>4</sup>Department of Rehabilitation Medicine, Akita University Hospital, Akita, Japan<sup>5</sup>Akita Prefectural Center on Development and Disability, Akita, Japan**ABSTRACT**

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**Objective:** We administered a conventional pointing-method test with eye-tracking to evaluate items associated with auditory comprehension and examined the concordance between the obtained results.

**Methods:** The enrolled participants were 10 healthy volunteers. We performed tests after extracting auditory comprehension items from the SLTA, the WAB, and the Supplementary tests for the SLTA using the eye-tracking system and the pointing method.

**Results:** The mean test duration was 9 min 51 s  $\pm$  1 min 41 s (mean  $\pm$  SD), and the percentage of correct answers was 100% and in perfect agreement for the pointing method and the eye-tracking system. The mean response time was 0.96  $\pm$  0.36 s for the pointing method and  $-0.39 \pm 0.21$  s for the eye-tracking system. Hence, the latter was faster than the former, and examinees completed their responses before listening to the end of the questions.

**Conclusion:** The new eye-tracking system makes it possible to perform aphasia tests (auditory comprehension items) comparable to the conventional pointing method.

**Key words:** eye-tracking, aphasia, standard language

test of aphasia, Western Aphasia Battery, feasibility study

**Introduction**

Aphasia occurs in approximately 21–38% of stroke patients [1]. There are currently 200,000–500,000 aphasia patients in Japan alone [2]. Only some 12–39% of patients can return to work after aphasia onset [3]. In these workers, this communication disorder can hinder effective social participation. However, it has been reported that aphasia is never comprehensively tested for some cases of mild aphasia, and it is therefore overlooked as the characteristic linguistic symptoms are not noticed [4]. Therefore, it is necessary to develop a novel method for effectively and efficiently assessing and diagnosing aphasia as part of rehabilitation care to avoid overlooking the condition.

The Japanese Guidelines for the Management of Stroke 2021 [5] recommend that the Standard Language Test of Aphasia (SLTA) [6] and the Japanese-language version of the Western Aphasia Battery (WAB) [7] should be used as standard aphasia tests. As a result, these tests have been frequently utilized. Both tests are comprehensive aphasia assessments that, in addition to the four linguistic functions of auditory comprehension, visual comprehension, vocalization/speech, and writing, include items that are unique to themselves. These tests require approximately 60–120 min to complete and are generally taken multiple times. The Supplementary tests for the SLTA [8] require approximately 60 min to complete.

In general, a pointing method is used for the auditory comprehension items in aphasia tests, in which the subject responds to the presented questions by pointing, but it is difficult to obtain appropriate results when the participant has upper limb motor disorders including severe quadriplegia. Hence, we have developed a new

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eye-tracking system that can be used to test for aphasia, including appropriate auditory comprehension items, even in patients with upper limb motor impairment.

Eye-tracking is an engineering technology that allows factors such as eye movement, the position of the line of sight, and abnormal line of sight patterns to be measured objectively [9]. Maruta et al. [10] reported that eye-tracking technology may be effective in assessing latent disorders of visual attention in patients with mild traumatic brain injury. To the best of our knowledge, there are no previous studies on the use of eye-tracking technology for aphasia tests for patients whose native language is Japanese.

The purpose of this study was to administer the auditory comprehension items of the aphasia tests (SLTA, WAB, SLTA assisted test) to healthy adults whose native language is Japanese using a newly developed eye-tracking system, compare the results with those of the conventional pointing method, and examine the feasibility of clinical application.

### Methods

The participants were 10 healthy volunteers whose native language was Japanese (5 males, 5 females, average age  $25.4 \pm 7.1$  years). The study exclusion criteria were history of epileptic seizures, trauma, stroke, or other conditions that can cause aphasia. Before the experiment, it was confirmed that there was no problem with the visual acuity of participants in general or with the use of vision correction devices in visual screening tests. The participants did not have hearing impairments or upper limb movement disorders that could have caused problems during aphasia testing in the current study.

The specific evaluation items in this testing system

are words, short sentences, hiragana (i.e., one of the two syllabaries in the Japanese language), shapes, numerals, colors, and yes/no questions that test auditory comprehension. The test items were taken from the test batteries mentioned above (SLTA, WAB, and Supplementary tests for the SLTA). The testing system evaluated in this study administered 64 items (68 questions) extracted from the aforementioned test batteries (Table 1).

The unique system developed by our group utilized for current aphasia testing included an eye-tracking device (Tobii X120®; Tobii Technology, Stockholm, Sweden), a laptop used to control the system (ThinkPad E490, Lenovo, Quarry Bay, Hong Kong), a 13.3-inch full HD LCD monitor with a refresh rate of 60 Hz, and a chinrest with a headrest that was used to minimize head movements (Figure).

The system links the eye-tracking device with the illustrations in aphasia testing that serve as the questions. One of the system's characteristic features is the measured line of sight information, which is captured by the infrared component displayed on the operating screen in real-time and recorded as testing data.

In the experiment, the eye-tracking system, which was calibrated before the start of the test, was used to record the gaze, and a video camera (HDR-CX675, SONY, Japan) was used to record the movements of the participants including pointing and eye movements at a frame rate of 60 fps. A pointing stick was also prepared to be used for pointing.

The procedure of the experiment was as follows. The participants listened to the examiner read out the aphasia test questions as usual and selected their answers by pointing with their eyes and using a pointing stick on the monitor for each test item. Staring was defined as gazing steadily for at least 100 ms.

**Table 1.** List of question items.

SLTA I. Listening		
1-1	Word comprehension	(10 questions)
1-2	Short sentence comprehension	(10 questions)
1-4	Kana comprehension	(10 questions)
WAB II. Comprehension of spoken words		
II-B Auditory cognition of words		
	Picture cards	(6 questions)
	Illustrations	(6 questions)
	Letters	(6 questions)
	Numerals	(6 questions)
	Colors	(6 questions)
Supplementary tests for SLTA		
(2)	Yes/No responses	(8 questions, 4 topics)

The problems having to do with auditory comprehension were extracted from the Standard Language Test of Aphasia (SLTA), the Western Aphasia Battery (WAB), and the Supplementary tests for the SLTA.

Immediately after the start of the eye-tracking, the examiner started reading the question, and the end of the question was confirmed by the waveform of the voice in the video data. The responses of the participants were recorded using the eye-tracking system and the recording video camera, and the correct and incorrect answers were scored the same way as before. We also recorded the duration from the start of the recording of the eye-tracking system, which was immediately before the start of the reading of questions, to the end of the reading; the movement of the gaze until the pointing with the pointing stick was completed; the choice of both gaze and pointing answers; and the time required for each answer. These data were compared to video recordings of the overall and eyeball movements of the participants to determine the presence of any contradictions of methodologies.

The timing of hand movement was determined by checking the video recording of the entire movement of the participant, and the time at which the participant

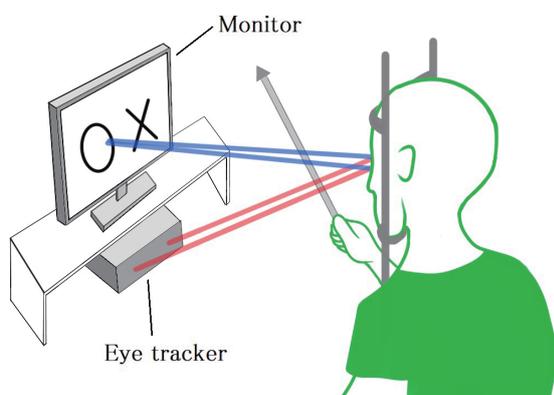
started to move toward the option to be pointed to later was determined subjectively by the examiner according to the conventional SLTA. In addition, the duration and timing of each action were analyzed by synchronizing the eye-tracking data with the video data and were determined based on the number of frame changes in the video by checking the elapsed time of the eye-tracking data.

The items to be examined were (1) the aphasia test time until the completion of all tests, (2) the percentage of correct responses by pointing and the eye-tracking system, (3) the time from the end of the reading of a question to the time when the hand started to move, and (4) the response time by pointing and the eye-tracking system starting from the time when the reading of a question was completed.

This study was approved by the Ethics Committee of Akita University Hospital (approval number 2221).

## Results

The mean testing duration was 9 min 51 s  $\pm$  1 min 41 s. The proportions of correct answers for the pointing and visual selection evaluations were 100% (Table 2). All responses were matched on comparison of the evaluation methodologies. None of the participants complained of poor physical conditions or fatigue after concluding the testing. The mean time that elapsed between the point at which the examiner finished reading the questions for each item and the point at which the participants started answering with the pointer was 0.05  $\pm$  0.23 s. The mean duration from the point at which the examiner finished reading the questions to the point at which the participants completed answering using the pointer was 0.96  $\pm$  0.36 s. In contrast, data assessed via the eye-tracking device showed that the mean time point at which the responses were visually selected was  $-0.39 \pm 0.21$  s while the participants were still listening to the questions being read. The mean time from the point after which the responses were visually selected until the point at which



**Figure.** Schematic diagram of the testing.

The test participants sat directly in front of the monitor and placed their faces on the chinrest to reduce head movement. The eye-tracking device beneath the monitor recorded the line of sight of the participant using an infrared camera. The test participant answered each item using a handheld pointer.

**Table 2.** Correct answer rate according to the response method and correct answer rate for healthy adults with the conventional pointing method as the referent.

		Eye tracking	Pointer	Face-to-face method* <sup>1</sup>
SLTA	Words	10	10	10.0 $\pm$ 0.2
	Short sentences	10	10	9.5 $\pm$ 0.8
	Kana	10	10	10.0 $\pm$ 0.1
WAB		30	30	59.9 $\pm$ 0.3* <sup>2</sup>
Supplementary tests for SLTA	Yes/No	4	4	4 $\pm$ 0

\*<sup>1</sup>Correct response rates for healthy adults were extracted based on methodology specified in the previous report [2–4].

\*<sup>2</sup>The total point score differs for this testing modality because only the 30 problems that could be displayed on the monitor were extracted in the present study. However, the auditory comprehension II-B: Words instrument contains 60 questions.

the participants started answering using the pointer was  $0.44 \pm 0.14$  s.

### Discussion

The present study is the first feasibility study of the newly developed eye-tracking system. In this study, auditory comprehension items of aphasia tests (SLTA, WAB, Supplementary tests for SLTA) were administered to healthy participants, and the results were compared with those of conventional pointing tests. The study showed that the results of the eye-tracking system and the pointing method were the same, and the completion time was shorter for the eye-tracking system.

For the items of auditory comprehension for aphasia testing, the mean scores for the portions of the SLTA that apply to healthy volunteers (according to a two-step correct/incorrect scale) were  $10.0 \pm 0.2$  points for the auditory comprehension of words,  $9.5 \pm 0.8$  points for the comprehension of short sentences, and  $10.0 \pm 0.1$  points for the comprehension for kana (hiragana), according to the guidelines specified in the testing manual. For the WAB, the mean score was  $59.9 \pm 0.3$  points (out of a total of 60 points; 30-point conversion:  $30.0 \pm 0.2$ ). The mean score was  $4 \pm 0$  out of 4 for the Supplementary tests for the SLTA. In this study, all participants provided correct responses to all questions without having the questions repeated and without receiving hints. This suggests that a system that utilizes eye-tracking can be used without concern in healthy individuals to assess their auditory comprehension within aphasia tests. In addition, the eye-tracking system is expected to facilitate the testing of participants who cannot be tested for aphasia by conventional pointing, such as patients with upper limb motor disorders including severe quadriplegia.

In this study, it was found that the aphasia test response time was shorter with the eye-tracking system than with the conventional pointing method, and the examinees completed their responses before the examiner finished reading the questions. Oyama et al. [11] reported that eye-tracking technology has applications in cognitive function testing. In this study, a rapid cognitive assessment using eye-tracking technology was used for quantitative scoring of cognitive disorders and was shown to offer outstanding diagnostic performance when used for dementia patients. Since this study involved healthy participants, studies of aphasia patients need to be conducted in the future to clarify whether swift assessment and quantitative scoring are possible and whether the diagnostic performance is excellent.

The limitations of this study and issues to be considered in the future are as follows. First, the average age of the participants was 25 years, which is different from the average age of aphasia patients. In the future, it will be necessary to validate the results in older healthy adults and patients suspected of aphasia. Another limitation was the experimental setup. Before the test, the distance between the monitor and the

participant is set to be optimal according to the physique of the participant. However, it may take more time for the participant to point since there are no illustrations in front of him/her. Therefore, pointing may have to be performed under unfavorable conditions compared to the conventional testing method. The time from the end of reading to the start of hand movement and the time from the end of reading to the end of answering the question were within the range that can be judged as normal in this study; it was considered that there was little influence on the evaluation of the rate of correct answer agreement between the eye-tracking system and pointing method. In the future, however, we would like to examine the time required for each task when the conventional method is used under conditions optimized for pointing. It is also necessary to conduct investigations of parameters such as eyeball movements and line of sight tracking in future studies. We did not investigate the selection process up to the point at which the subjects began staring and we likewise hope to investigate movements of the line of sight after pointing. These concerns should be evaluated in future studies.

In this study, we evaluated the auditory comprehension domain of the aphasia test. However, we did not use real objects, such as furniture, stationery, and the body parts of the participants in the test room, because pointing on the monitor display cannot replace answering the questions while confirming disorders other than aphasia (e.g., apraxia). Therefore, it will be necessary to study how to incorporate the results of auditory comprehension assessment using the eye-tracking system into the overall aphasia test. However, the eye-tracking system developed in this study can be used to evaluate aphasic patients with upper limb motor disorders and is expected to be useful in clinical practice.

In conclusion, we have shown that the newly developed eye-tracking system can perform aphasia tests (auditory comprehension items) as well as the conventional pointing method in healthy individuals. The results suggest that the newly developed aphasia test can be applied to patients with upper limb motor disorders, including severe quadriplegia, which has been difficult to evaluate in the past. We would like to consider its clinical application going forward.

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