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Can Japanese Patients with Aphasia Who Can Read Individual *kana* Characters Correctly also Read *kana* Nonwords Correctly?

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ABSTRACT

According to the dual route model, visually presented words are first analyzed by the orthographic analysis system. In this analysis system, the relationship between letter identification and word identification is not known. Two models are proposed: the serial letter model and the parallel letter model. Which model is correct remains controversial. If the letters in a word are processed serially (serial letter model), Japanese patients with aphasia who can read individual *kana* characters correctly should be able to read any *kana* nonword correctly, because these patients have no impairment in the grapheme-to-phoneme conversion system in the dual route model. If the parallel letter model is correct, these patients cannot always read any *kana* nonword correctly. We asked 9 Japanese subjects with aphasia to read nonwords with varied interletter spacing. We found that the reading of nonwords with wide interletter spacing (corresponding to each character being presented separately) was more accurate than the reading of nonwords with narrow interletter spacing (corresponding a string of characters presented simultaneously). This result suggests that Japanese patients with aphasia who can read individual *kana* characters correctly cannot always read any *kana* nonword correctly. Our results support the parallel letter model.

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Key words: aphasia, *kana* (phonogram), nonword reading, letter identification, crowding phenomenon, dual route model

INTRODUCTION

According to the dual route model of language-processing, proposed by Patterson and Shewell[1], visually presented words are first analyzed by the orthographic analysis system[1]. A basic issue concerning the identification of words is the relationship between letter identification and word identification in this analysis system. Much research has been guided by two simple models of word recognition: the serial letter model and the parallel letter model[2]. To simplify future discussion, we assume that there are representations in the brain, called letter detectors and word detectors (that is, some reproducible pattern of neural activity that occurs when a given letter or word is identified), and rephrase the questions in terms of the relationship between letter detectors and word detectors; we will also use the term "letters" to refer to Japanese characters as used in this study. In the serial letter model, letter recognition is a stage

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before word recognition, and the letters in a word are processed serially (usually hypothesized as going from left to right, as in English). In the parallel letter model, letter detectors are activated, and the letter information is fed in parallel to word detectors. When the excitation from component letter detectors is sufficiently strong, the appropriate word detector is activated. Which model is correct remains controversial.

The Japanese writing system consists of phonograms (*kana*) and morphograms (*kanji*)[3]. The relationship between orthography and phonology in *kana* is perfectly regular and rule-governed[4]. Nearly all *kana* characters can be combined in whatever sequence or order desired to make pronounceable nonword strings. As individual *kana* characters have no meaning, both individual *kana* characters and *kana* nonwords are processed by the grapheme-to-phoneme conversion system (GPC system). In the GPC system, the grapheme is converted to a corresponding phoneme[1]. Japanese patients with aphasia who can read individual *kana* characters correctly have no impairment of the GPC system. If letter identification of a nonword is a stage before nonword identification and if the letters of a word are processed serially (serial letter model), Japanese patients with aphasia who can read individual *kana* characters correctly must be able to read any *kana* nonword correctly. If the parallel letter model is correct, these patients cannot always read any *kana* nonword correctly. In the present study, to determine which model is correct, we examined whether Japanese patients with aphasia can always read any *kana* nonword correctly. Because healthy persons without aphasia can read all *kana* nonwords correctly regardless of interletter spacing, patients with aphasia were chosen as subjects.

We asked 9 Japanese subjects with aphasia to read nonwords with varied interletter spacing. When persons are shown a string of letters with the usual interletter spacing (for example, 1 mm), they look at all the characters simultaneously as a single string. On the other hand, when persons are shown a string of letters with unusually wide interletter spacing (for example, 70 mm), they look at each letter separately. The latter situation corresponds to reading a single *kana* character, because the distance between two adjacent letters is wider than the "functional visual field of reading." The "functional visual field of reading" is the size of the visual field within which textual recognition occurs without eye movements during normal reading[5].

Patients with brain damage can have several types of visual disorder. For example, some patients with cerebrovascular disease show a specific visual acuity disturbance called crowding phenomenon[6], in which visual acuity is normal for symbols presented with wide spacing but is decreased for symbols presented with narrow spacing[6]. Bandoh et al. have reported on three patients with cerebrovascular disease who exhibited the crowding phenomenon[7]. We asked subjects with aphasia to read nonwords with varied interletter spacing. If the subjects were to make more mistakes when reading characters presented with narrow interletter spacing than with wider interletter spacing, they might have the crowding phenomenon. In the present study, therefore, we examined whether our subjects with aphasia showed the crowding phenomenon.

METHODS

Experiment 1

Subjects

We administered the Japanese Standard Language Test of Aphasia[8] to all patients with aphasia admitted with cerebrovascular disease (unilateral left-sided lesion) to The Jikei University Hospital, Fuchu Hospital, or Nansho Hospital from July through October 1998. From among these patients, we selected 9 subjects (Table 1) who could read all individual *kana* characters correctly in our task. These 9 subjects were examined from 5 months to 7 years after the onset of cerebrovascular disease. The type of aphasia was determined with Japanese Standard Language Test of Aphasia. Five subjects had Broca's aphasia, 3 had Wernicke's aphasia, and 1 had conduction aphasia. All subjects were confirmed to be right-handed and to have no visual field defects.

Table 1. Subjects

patient	age	sex	type of aphasia	etiology/lesions
1	61	female	Wernicke	left temporoparietal infarction
2	75	female	Broca	left putaminal hemorrage
3	58	male	Broca	left putaminal hemorrage
4	63	female	Broca	left putaminal hemorrage
5	43	male	Broca	left putaminal hemorrage
6	75	female	Wernicke	left putaminal hemorrage
7	72	male	Wernicke	left putaminal hemorrage
8	57	female	Broca	left frontoparietal infarction
9	57	male	Conduction	left parietal lobe hemorrage

The cause of cerebrovascular disease was either cerebral infarction or hemorrhage. All subjects had had at least an elementary school education. Informed consent was obtained from all subjects before their participation in this study.

Testing

To create *kana* nonword stimuli, we randomly selected 25 groups of four *kana* 'letters' from the 46 basic *kana* characters. We prepared each *kana* nonword with five different interletter spacings: 1, 5, 15, 30, and 70 mm. Thus, the total number of stimuli was 125. We printed each of the nonwords at the center of a page of A4-sized paper (297×210 mm).

The stimuli were presented to the subjects on a desk at a reading distance of 48 cm. Each letter (1 cm tall and 1 cm wide) subtended a visual angle of 1°. The visual angles for the four letters subtended by the five types of stimulus were 5°, 6°, 10°, 14°, and 27°, respectively. When Japanese read *kana* strings, the visual angle of the functional visual field of reading is about 5°[9]. In our experiment, when the width of four *kana* letters in a word was within 5°, all four letters were seen simultaneously in the functional visual field of reading. In our method, for the narrowest interletter spacing, the visual angle of the four *kana* letters was 5°. Thus, all four *kana* characters in each word were seen simultaneously within the functional visual field of reading. In contrast, if the width of two adjacent *kana* letters was greater than the functional visual field of reading, each individual character would be read separately. For the widest interletter spacing, the visual angle of two adjacent letters was 8° (larger than the functional visual field of reading); therefore, each *kana* character was read separately. All 125 stimuli were presented to the subjects in random order. The subjects read these *kana* nonwords aloud, and their responses were recorded in the order reported.

Scoring was done as follows. The subject received 1 point for reading each *kana* letter correctly, regardless of the letter position. Thus, the subject was given 4 points for reading one four-letter non word correctly. We calculated mean scores for each interletter spacing.

Statistical analysis was performed with a linear model to evaluate the association between the mean scores for each interletter spacing, with the following equation:

$$Score_{ij} = \mu + \beta \times Spacing + \gamma_i + \delta_j + \varepsilon_{ij}$$
$$(i=1, ..., I\ ;\ j=1, ..., J)$$

where γ_{ij} is an effect parameter of i-th patient, δ_j is an effect parameter of j-th nonword, I is the number of patients, and J is the number of nonwords.

Experiment 2

Subjects

We obtained informed consent for participation in experiment 2 from five of the nine subjects who participated in experiment 1.

Testing

We examined whether the subjects showed the crowding phenomenon by using "Yamazi-trennungs trainer" visual charts[10,11] (Fig. 1). We used two charts, with the figures separated by 8 mm (Fig. 1a) or by 45 mm (Fig. 1b). Each chart contains E's equal in size to that of the Snellen letter 0.8 as seen from a distance of 5 m.

We measured the visual acuity for the chart with the 45-mm separation on the basis of the longest distance from which the subject's answers were correct at least four out of five times. First, the subject

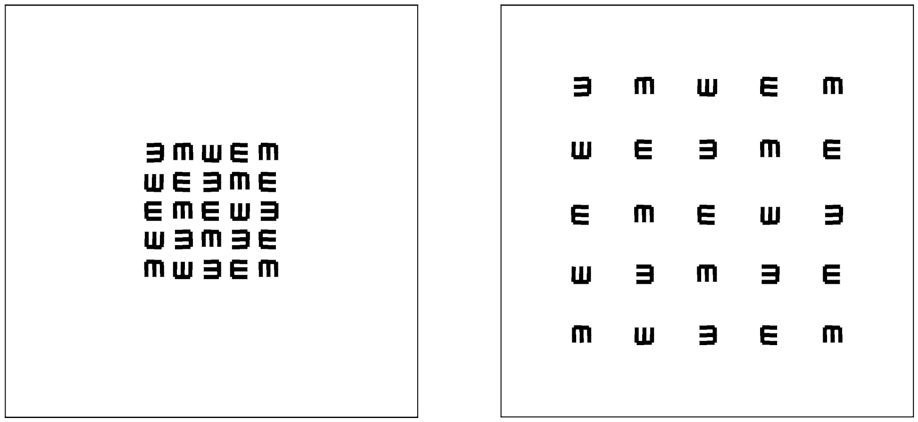

Fig. 1a Fig. 1b

Fig. 1. The charts of Yamazi-trennungs trainer. The amounts of separation were 8 mm (Fig. 1a) and 45mm (Fig. 1b) between the figures.

was shown the chart from a distance of 2 m and asked to tell the direction of the E's. Each subject looked at the target with both eyes. We tested the target direction five times at the 2-m distance. If the answer was correct at least four out of five times, acuity was tested at a 2.5 m.

We calculated visual acuity as follows. If a subject correctly determined the direction of the E's from a distance of 5 m, visual acuity was 0.8. If a subject correctly determined the direction of the E's from a distance of 2.5 m, visual acuity was 0.4.

We next performed the test and calculated visual acuity in the same way using the chart with an 8-mm separation between the figures from a distance of 2 m.

If our subjects showed the crowding phenomenon, the visual acuity measured with the chart with a 45-mm separation between figures would be better than that measured with the chart showing an 8-mm separation. When the dissociation between the two visual acuities was greater than 0.2, the patient was judged to have the crowding phenomenon[11].

RESULTS

Experiment 1

Results in detecting statistically significant positive trend of score with regard to inter-letter spacing were $\hat{\beta}=0.00569$, P-value$=7.35\times10^{-6}$. The reading accuracy of *kana* nonwords by all subjects was better with wide interletter spacing than with narrow interletter spacing regardless of the site of brain lesion or type of aphasia (Fig. 2).

Experiment 2

No subjects showed dissociation of the visual acuity by more than 0.2. Thus, none of the subjects exhibited the crowding phenomenon.

DISCUSSION

Our major findings were as follows. Reading of nonwords was more accurate with wide interletter spacing (corresponding to each character being presented separately) than with narrow interletter spacing (corresponding to a string of characters simultaneously presented) regardless of the type of brain lesion or aphasia. This result might have been due to the crowding phenomenon. The crowding phenomenon refers to patients having normal visual acuity when symbols are widely spaced but having decreased visual acuity when symbols are narrowly spaced. However, because our subjects did not exhibit the crowding phenomenon in experiment 2, the result of experiment 1 could not be attributed to the crowding phenomenon.

To our knowledge, our study is the first systematic investigation of the relation between a reading

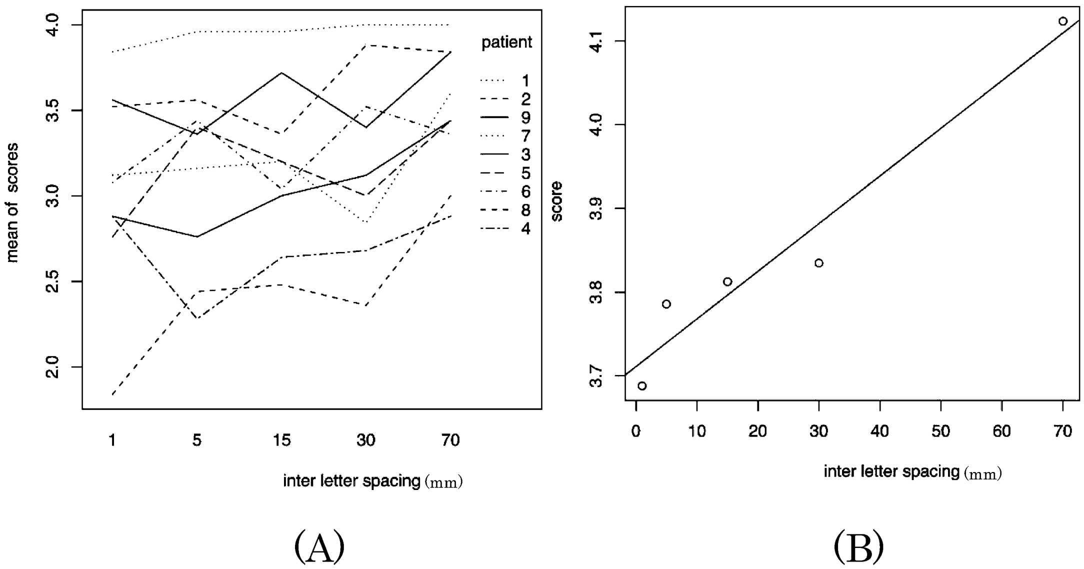

Fig. 2. The association between the mean of scores and the inter-letter spacing for each subject (A) and all subjects (B).

disorder and interletter spacing in patients with general aphasia. However, one earlier study has examined this relation in patients with pure alexia[12]. Pure alexia is among the most common peripheral reading disturbances[13], whereas patients with aphasia have central reading disturbances. Some investigators have attributed pure alexia to a visual impairment that prevents activation of orthographic representations[14]. Thus, because pure alexia is thought to be quite different from the reading disturbances of patients with aphasia in our study, a discussion of pure alexia is not relevant here.

We found that Japanese patients with aphasia who can read individual *kana* characters correctly cannot always read any *kana* nonword correctly. This result shows that in the orthographic analysis system, letter detectors are activated and letter information is fed in parallel into word detectors. Our result supports the notion that the activation from these letter detectors is sent in parallel to the word detectors (parallel letter model) in Japanese *kana* reading.

The parallel letter model has gained support from several studies. Reicher has reported that when the duration of stimulus exposure is controlled, letters in words are more accurately identified than are letters in isolation[15]. That identification is more accurate for letters in words than for the letters in isolation indicates that letters in words are processed in a parallel manner rather than in a serial manner.

To our knowledge, the only previous study of nonword identification is that by Goryo[16]. He presented *kana* words, *kana* nonwords, and *kanji* words to healthy Japanese readers with a tachistoscope and measured the time from when subjects were presented with nonwords to when they began reading aloud. He found that when healthy Japanese subjects read *kana* words, *kana* nonwords, or kanji words, the reaction time for reading aloud increases with the number of letters. Goryo argued that when Japanese subjects read even *kana* nonwords, the entire string is processed as a unit, regardless of whether the string consists of words or nonwords[16]. The serial letter model cannot explain Goryo's findings.

Conclusion

We found that in Japanese patients with aphasia, the reading of nonwords with wide interletter spacing (corresponding to each character being presented separately) is more accurate than the reading of nonwords with narrow interletter spacing (corresponding to a string of characters presented simultaneously), regardless of the type of brain lesion or aphasia. Japanese patients with aphasia who can read individual *kana* characters correctly cannot always read any *kana* nonword correctly. However, the greater accuracy for the reading of *kana* nonwords with wider interletter spacing cannot be attributed to the crowding phenomenon. Our results support the parallel letter model in the word recognition system for Japanese *kana* reading.

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