

Disorder in Sequential Speech Perception: A Case Study on Pure Word Deafness

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We described disorders of a patient which were uniquely restricted to speech perception of syllable sequences after brain damage. The results of series of experiments using syllable sequences showed “negative recency effect,” in which the subject’s repetition performance at the latter syllable position was remarkably poor. Experimental analyses suggested that the “negative recency effect” could be due to dual factors: the lower rate of processing of speech sounds and the memory load of holding processes of preceding syllables imposed on the succeeding phonological processing. The results also suggested that the holding processes which imposed the memory load on the succeeding auditory phonological coding processing were modality nonspecific. © 2001 Academic Press

INTRODUCTION

Most neuropsychological studies on cognitive processes of speech sounds have been mainly focused on impairments of perceiving monosyllables. Most of them researched patients with pure word deafness (Albert & Bear, 1974; Auerbach, Allard, Naeser, Allexander, & Albert, 1982; Notoya, Suzuki, Furukawa, & Enokido, 1991; Tanaka, Yamadori, & Mori, 1987; Saffran, Marin, & Yeni Komshian, 1976; Caramazza, Berndt, & Basili, 1983). Albert and Bear (1974) and Auerbach et al. (1982) emphasized that the defect in auditory temporal resolution played an important role for the development of pure word deafness. They found that patients with pure word deafness were markedly impaired in detecting gaps between acoustic stimuli. Notoya

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et al. (1991) and Tanaka et al. (1987) suggested that besides this deficit, the difficulties in loudness discrimination and pitch discrimination may also cause word deafness. These authors have emphasized defects in acoustic level as the underlying defect in pure word deafness. On the other hand, Denes and Semanza (1975) and Saffran et al. (1976) emphasized the role of phonemic discrimination. Auerbach et al. (1982) reviewed previous reports and suggested that there are two distinct types of pure word deafness: type 1, in which the deficit is prephonemic and related to an auditory temporal acuity disorder; and type 2, a form that has a deficit in linguistic discrimination, independent of an auditory temporal acuity disorder.

Speech, however, consists of a series of syllable sequences. Therefore, it is essential to analyze this type of disorder experimentally in order to understand the cognitive processes of speech. Recently we encountered a unique patient whose language deficiencies could not be explained by a deficit in monosyllable perception. Instead, impairment in processing syllable sequences was found to be critical for this case. We examined this subject's sequential syllable perception in an effort to clarify the mechanism.

CASE REPORT

The patient KT was a 42-year-old right-handed male who had been working as an engineer after earning a Master's degree. He had a left subcortical hemorrhage, and underwent surgery to remove hematomas twice in 1988. He showed right hemianopsia and right hemiplegia. Although postoperatively he manifested Wernicke's aphasia, 1 year later his language ability had recovered well; he scored full marks in each subtest of the Standard Language Test of Aphasia (Nirayama Conference, 1975) except for several subtests using auditory channel. His main complaint was a frequent failure to catch syllables in unfamiliar words in his daily life, and this listening disturbance remained even in 1995. An MRI performed in 1993 revealed a focal lesion in the left putamen (Fig. 1). He scored above average on a WAIS-R conducted in 1988, showing no overall deficiency in intelligence (VIQ = 114; PIQ = 104; questions were presented visually). Pure tone test and auditory brain-stem responses were within normal range for both ears. No abnormalities were found in our screening tests for recognition of environmental sounds and musical melody. Furthermore KT could detect 3-ms gaps on a gap detection test (Penner, 1977), and it showed that his temporal acuity was normal. KT could perceive Japanese monosyllables with an accuracy rate of 85%.

EXPERIMENTAL INVESTIGATION

Experiment 1 Repetition Tasks

We considered it strange that, compared to his ability of perception of monosyllables, his mistakes of catching words were very frequent in daily conversation. So to examine KT's listening disturbances further, repetition tasks were conducted.

Stimulus materials. Two- to four-syllabic familiar words (nouns) and nonwords¹ were used. Thirty words were presented for each type.

Subjects. KT and two persons with peripheral hearing disorders who were employed as controls were the subjects.

Procedure. Each stimulus was presented orally by a female instructor in the free field at normal speech rate. In advance the information whether the stimulus was a real word or a nonword was given to the subjects. The subject was asked to repeat the words immediately.

¹ Most Japanese nouns or verbs consist of two to seven monosyllables which are similar to vowel combinations or CV syllables in English, so the stimuli we used here have the same syllable components as real words.

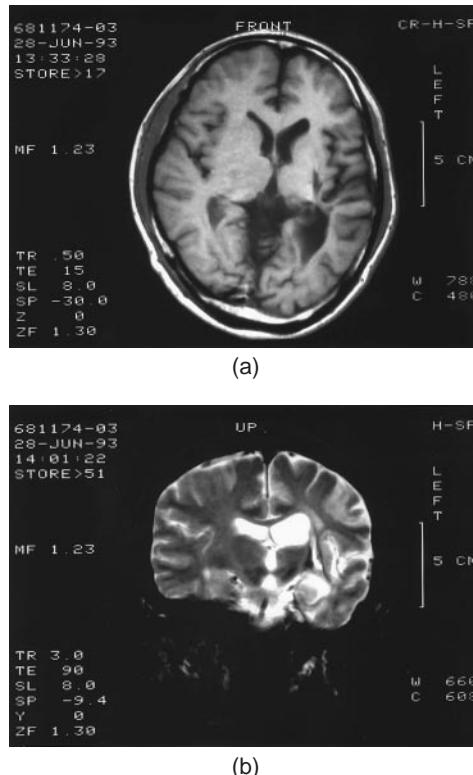


FIG. 1. MR brain scan showing restricted lesion of putamen and dilatation of left lateral ventricle on axial and coronal slices.

Results and discussion (see Figs. 2a–2c). KT and the control subjects showed difficulty repeating nonwords compared to real words. This can be explained by the fact that KT and the control subjects had intact semantic systems, and for real words, they could take advantage of the semantic cues. A striking feature of KT's results was the pattern of errors for nonwords. The accuracy of repetition declined as a function of syllable positions. Errors were mostly substitutions with a syllable quite dissimilar to the target syllable (for example, /tasajiko/ → /tasanina/; /soyayuho/ → /sohayabu/), and according to the results of error analysis we could not find any systematic error such as replacement of the syllable orders. By contrast this tendency was not shown by the two control subjects. Provisionally we use the term "negative recency effect" to refer to KT's error pattern in nonwords, in contrast to the recency effect in a free recall test.

How could we explain the negative recency effect in repetition tasks performed by KT? We think there are three explanations. The first is that the declination could be due to a faster-than-normal decay rate in the holding process of phonological information; that is, he forgets "recent," or latter, syllables while he reports "primal," or earlier, syllables. The second is that it could be due to limited capacity in phonological storage, and the third is that it could be due to disturbance of phonological coding processes for "recent syllables" or syllables that occur later in a sequence. To explore these possible explanations, we conducted the following three experiments.

Experiment 2 Backward Repetition Tasks

At first we examined the first explanation using backward repetition. As Japanese words can be easily decomposed into monosyllables which are similar to CV syllables in English, any words can be pronounced "backward" using such monosyllables as pronunciation units. In these tasks subjects were asked to report the last syllables in a stimulus nonword at first, so if KT's deficit were present in the holding process, the accuracy of the last syllables might improve.

Stimulus materials and subjects. These were the same as for Experiment 1, except that four-syllabic nonwords were not presented. In four-syllabic nonwords, it was too difficult for subjects to perform this task and no responses were often seen.

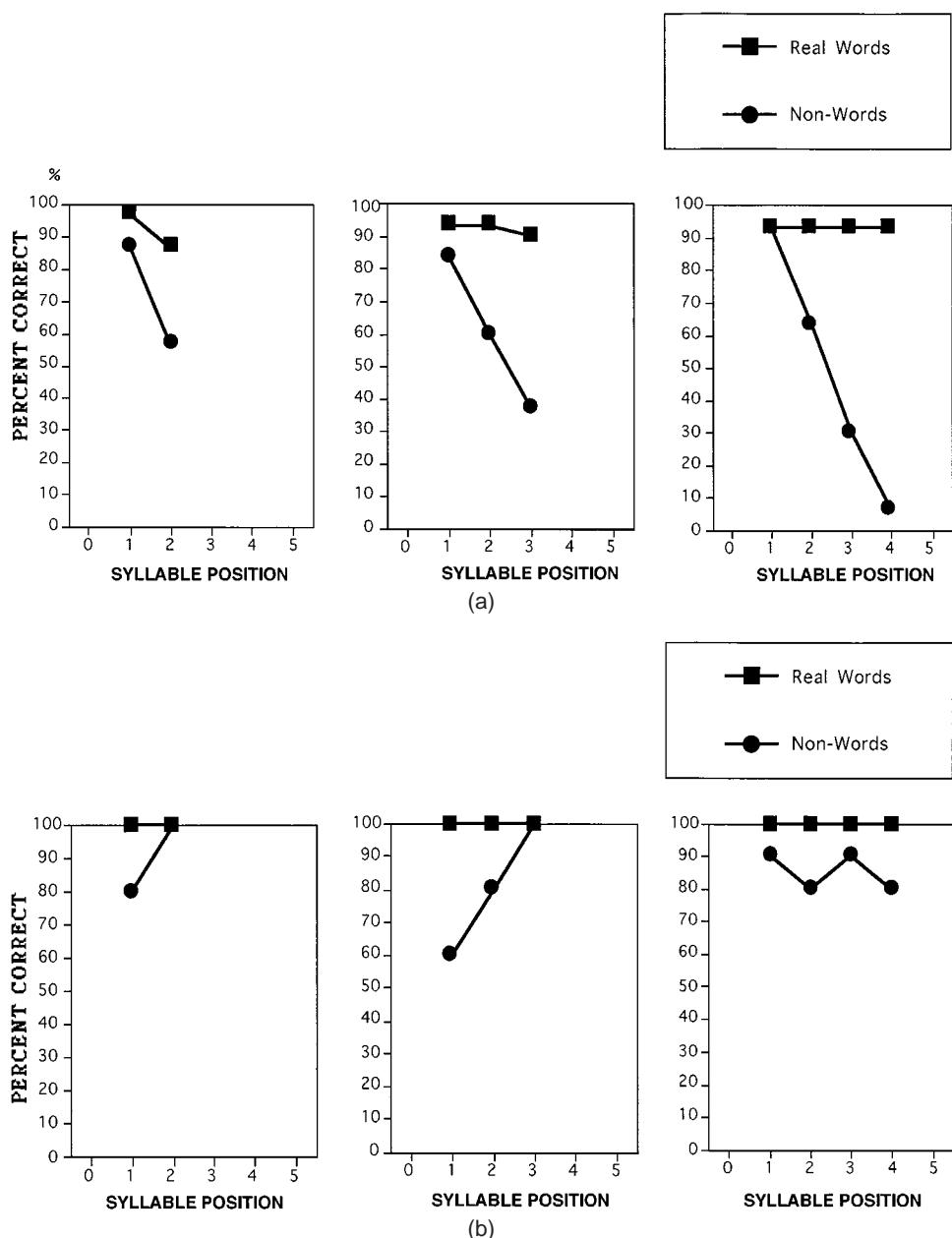


FIG. 2. (a) Results of repetition tasks in KT. (b, c) Results of repetition tasks in two control subjects with peripheral hearing disorders. The negative recency effect was not found in these subjects.

Procedure. KT and control subjects were asked to repeat words "backward."

Results and discussion (see Fig. 3). KT showed a negative recency effect again in two- or three-syllabic nonwords in this "backward" repetition task (Fig. 3a). For the preceding syllables in a word that were heard earlier but were reported later, KT showed no difficulties and generally was successful, but again had difficulty reporting the syllables in the last syllable position that he was asked to report first. The control subjects yielded no such pattern of performance (Figs. 3b, 3c). Thus the negative recency effect found in the forward repetition cannot be attributed to the deficits of the holding process for phonological information. That is, it is unlikely that he had forgotten syllables in the latter syllable position while reporting earlier syllables.

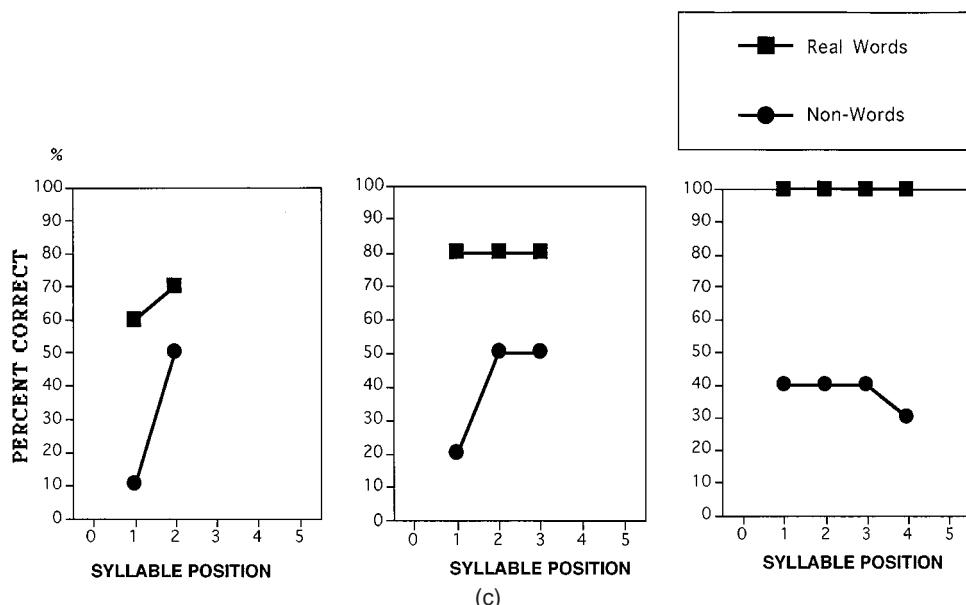


FIG. 2—Continued

Experiment 3 Reading Tasks

This experiment examined KT's phonological storage capacity by using visually presented syllable sequence stimuli.

Stimulus materials. One hundred twenty nonwords composed of four syllables were used.

Subject. KT was the only subject.

Procedure. On each trial, four different kana letters (each represents a Japanese monosyllable) were presented in succession on a computer-controlled tachistoscope display. Each kana letter was presented for 150 ms on a tachistoscopic display. Every time kana letter was removed, a mask stimulus, [&], was presented for 50 ms. After the mask stimulus, there was a 300-ms blank, and the next letter was presented on the right side of the former letter. Four letters in each trial were located at different places on the tachistoscopic display. KT was to report orally all the letters after they had been presented and removed.

Results and discussion (see Fig. 4). KT's scores were very good for all the serial positions. In addition to intact visual coding processing from letters to speech sounds, his phonological storage capacity was large enough to retain a four-unit syllables for oral reporting. His negative recency effect in repetition, therefore, could not be explained by a limited phonological storage capacity. Therefore the second possible explanation was eliminated.

Experiment 4 Repetition Tasks and Syllable Matching Tasks with Varied Presentation Intervals

The remaining possibility, then, is that KT has a deficit in phonological coding processes. We assumed that he would not have enough time to build phonological representations for "recent" syllables, because processing of primal syllables would consume an inordinate amount of time, given the natural speed of sequential presentation. If so, then his scores for recent syllables would be likely to improve when stimuli were presented by separating the component syllables with longer intervals. This hypothesis was tested by varying stimulus onset asynchrony (SOA).

Repetition task: stimulus materials. Thirty nonwords composed of four syllables were used for each SOA.

Subject. KT was the only subject.

Procedure. SOAs were set at 250, 500, 1000, and 2000 ms. Each syllable length was about 250 ms under any condition. KT was asked to repeat the auditorily presented stimuli.

Results and discussion (see Fig. 5a). KT's scores improved slightly but the negative recency effect was still found even with the longest intervals.

In all the experiments described above, retaining earlier syllables could have interfered with processing

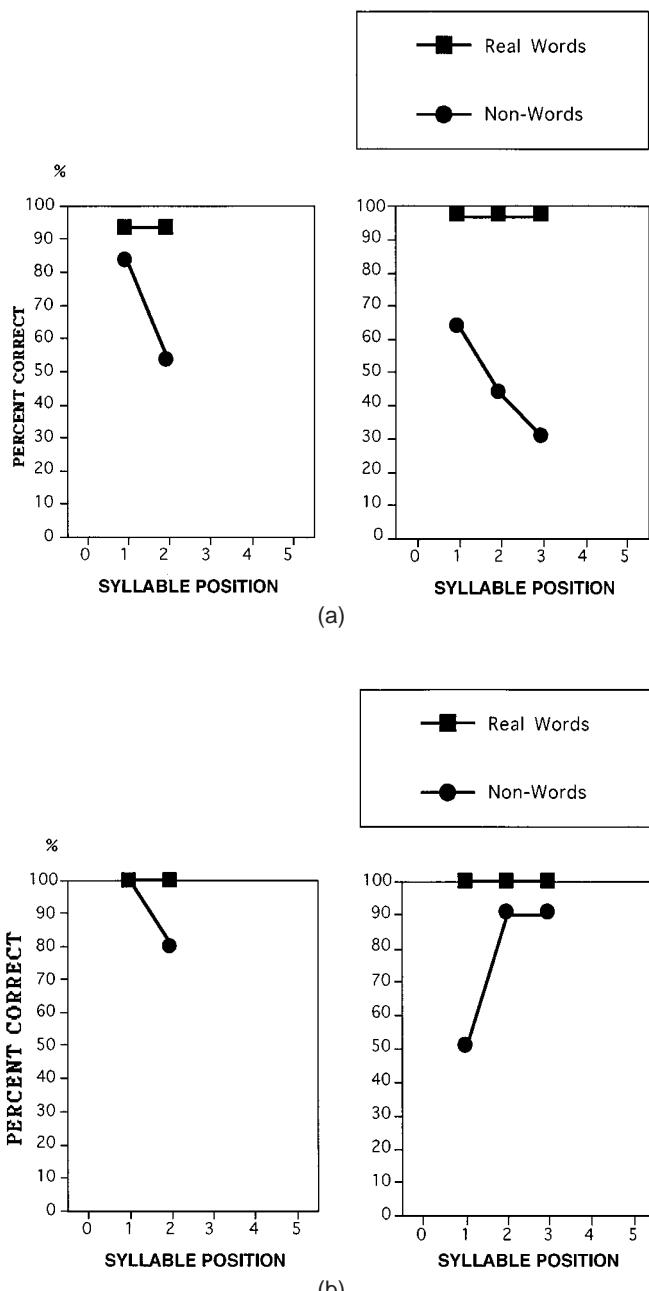


FIG. 3. (a) Results of backward repetition tasks in KT. The X axis shows syllable position of stimulus. KT reported from the right to the left in X axis. The syllables presented earlier were produced better while KT reported later. These results do not support that KT's holding processes of phonological information are disturbed. (b, c) Results of backward repetition tasks in two control subjects. The control subjects did not exhibit KT's pattern of performance.

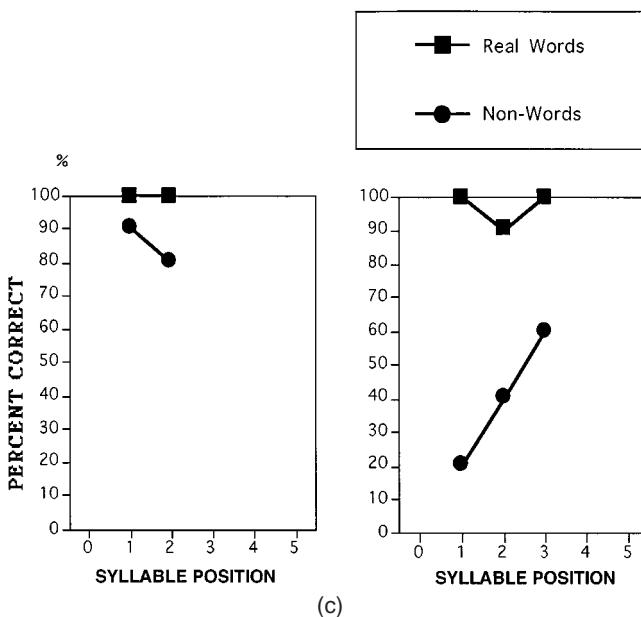


FIG. 3—Continued

latter syllables, as KT was asked to report all components presented. To examine this possibility, we conducted syllable-to-syllable matching tasks.

Syllable matching tasks: stimulus materials. One hundred eighty nonwords composed of four syllables for each SOA were used. Among the stimuli, 120 nonwords had a target syllable embedded in one of four syllable positions and 60 nonwords had no target syllables.

Subject. KT was the only subject.

Procedure. SOAs were set at 250, 500, 1000, and 2000 ms. After a target syllable was given in print in advance, a stimulus was auditorily presented. KT was asked to judge whether the target was contained in the stimulus. Five target syllables were used.

Results and discussion (see Fig. 5b). KT's scores of no target syllable trials showed over 90% correct through these tasks. Therefore it could be judged that his responses were reliable. Under conditions where SOAs were longer than 1000 ms, the negative recency effect disappeared; that is, KT earned over 90% correct for syllables in all positions. This pattern of performance supports the hypothesis posed above that the rate of phonological coding process should be lower.

Then why in the repetition tasks did his performance for recent syllables not improve to a normal level even in slow presentations? In the repetition tasks, KT had to retain all syllables and to repeat

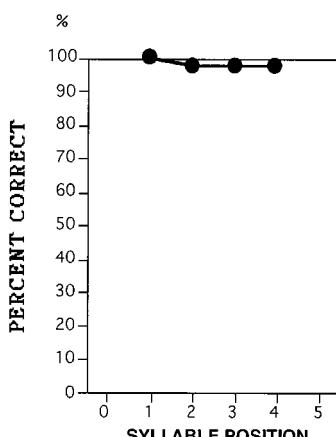


FIG. 4. Results of visually presented tasks in KT.

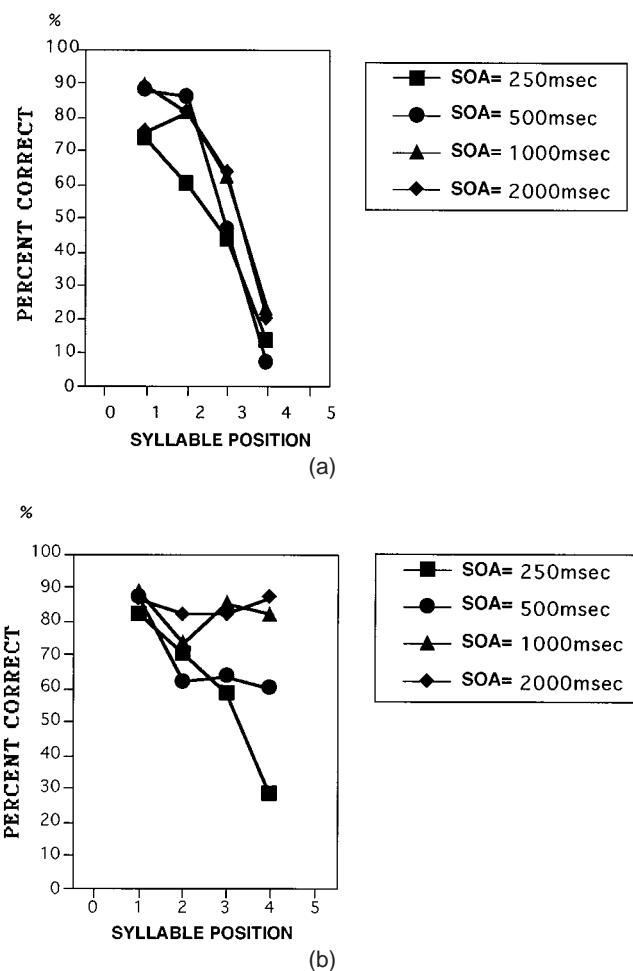


FIG. 5. (a) Results of repetition tasks varied in SOA. The negative recency effect was found even with the longest intervals. (b) Results of matching tasks varied in SOA. In this task the scores of later syllables improved under the condition that SOAs exceeded 1000 ms.

them. In the matching tasks, on the other hand, KT did not have to retain all syllables, because this experiment was designed to judge only whether the target was contained. Therefore it could be suggested that the retention of earlier syllables might affect the processing of recent syllables. Let us call this "memory load hypothesis." To confirm it further, we conducted a final experiment in which two conditions were set using different combinations of modalities for presenting a stimulus composed of four syllables.

Experiment 5 Visual and Auditory Tasks

Stimulus materials. Thirty nonwords composed of four syllables were used for each trial.

Subject. KT was the only subject.

Procedure. Under the first condition, the first and second two syllables were presented visually in print and the third and fourth two syllables were presented auditorily (V-A condition). Under the second condition the first and second two syllables were presented auditorily and the third and fourth two syllables were presented visually (A-V condition). KT was asked to report all the syllables orally immediately after a complete sequence was presented. The SOAs were set at 500, 1000, and 2000 ms.

Results and discussion (see Fig. 6). Under the V-A condition performance for the third and fourth two syllables was poor; thus the negative recency effect was found again. In contrast, under the A-V condition, the third and fourth syllables were reported very accurately. The percentage correct of the third and fourth syllables under the V-A condition was lower than that of the first and second syllables

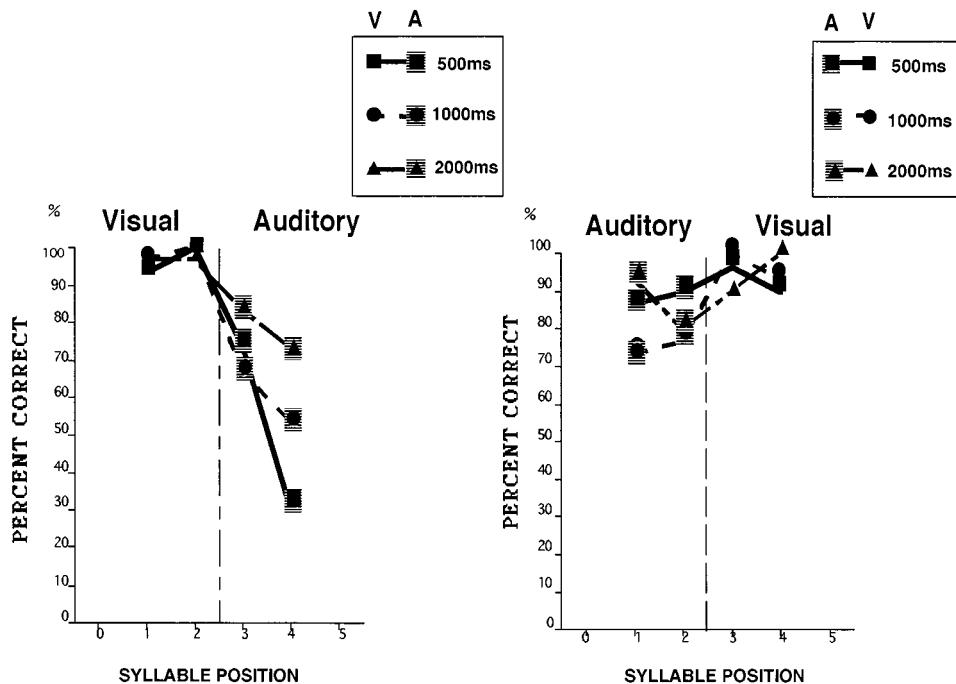


FIG. 6. Results of auditory-visual tasks in KT. Under the first condition, the first two syllables were presented visually in print and the last two syllables were presented auditorily (V-A condition). Under the second condition, the first two syllables were presented auditorily and the last two syllables were presented visually (A-V condition). KT was asked to report all the syllables verbally immediately after a complete sequence was presented.

under the A-V condition. This pattern of performance suggested that the retention of earlier syllables interfered with the processing of latter syllables presented auditorily, regardless of whether the primal syllables were presented visually or auditorily. The memory load hypothesis, therefore, is supported. But memory load should not affect phonological processing of latter syllables presented visually.

GENERAL DISCUSSION

The main points of our findings can be summarized as follows. First, KT had no deficit in acoustic temporal resolution, which have been considered to play an important role for patients with pure word deafness as a result of bilateral lesions. Although KT preserved fairly good ability to perceive monosyllables, he had remarkable difficulties in perceiving nonsense syllable sequences, showing the "negative recency effect" in repetition tasks. KT's repetition performance at the latter syllable position in a nonword was remarkably poor. The effect disappeared only when stimuli were presented slowly and retention of earlier syllables was not required, as shown in the matching tasks. These findings suggested that KT's disorders could be explained by dual factors: a lowered rate of speech processing, and some interferences made by retained earlier syllables. That is, KT could not make phonological code for latter syllables because he took longer to make phonological codes for earlier syllables. Moreover, retention of earlier syllables somehow interfered with the phonological coding process of latter syllables (Fig. 7).

This case is classified as "pure word deafness" or "phonemic deafness" because his disorder was restricted to speech perception without severe hearing loss, although his disorder was extremely mild. As we related in the Introduction, recent neuro-

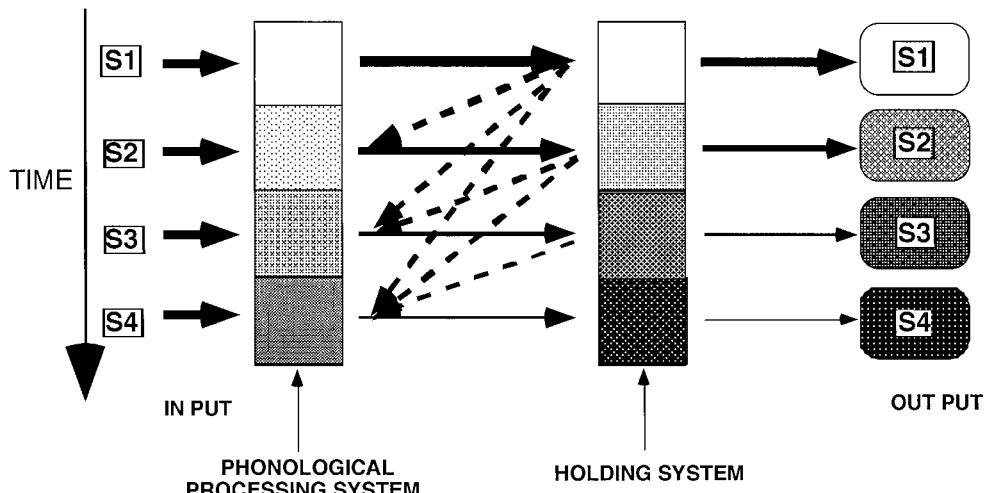


FIG. 7. Model of speech sound processing in KT. S1, first syllable; S2, second syllable; S3, third syllable; S4, fourth syllable. Dashed arrow shows the interference.

psychological research on word deafness has focused mainly on the analysis of mono-syllable perception. Although a few earlier studies suggested that comprehension of patients with word deafness improved to some degree when the speech rate was slow (Albert & Bear, 1974; Okada, Hanada, Hattori, & Shoyama, 1963; Metz-Lutz & Dahl, 1984), little attention has been paid to the deficits in sequential speech perception. We believe that KT's case may shed some additional light on understanding of pure word deafness.

According to Bub, Daniel, and Arguin (1995), in patients with pure alexia, or letter-by-letter reading, word length greatly affects response time. Such patients needed 3 or 4 s to read even common three-letter words and response time increased by 2 or 3 s for one additional letter. Although there are differences in information processing between visual and auditory tasks, KT's negative recency effect is very similar to the effects in pure alexia, because both types of patients are characterized by slow performance. Generally speaking, in visual tasks, all materials that compose words are presented simultaneously, while in auditory tasks, each syllable is presented one by one. Therefore, it could be that in visual tasks the lower rate of processing presents as increased response time, whereas in auditory tasks it presents as errors in latter syllables. Moreover, there is the discrepancy that KT could have utilized cues for word meaning, but a patient with pure alexia could not. We think further studies comparing with both visual and auditory disorders will be beneficial for understanding mechanisms of information processing in brain-damaged patients.

Furthermore, memory-to-perception interference might offer a new point of view about the function of working memory (Baddeley & Wilson, 1993). The relationship of speech perception and short-term memory has been recently discussed by many researchers. Allport (1984) and Friedrich et al. (Friedrich, Glenn, & Marin, 1984) argued that short-term deficits were inseparable from speech perception deficits. On the other hand, Vallar and Baddeley (1984a,b), and Randi and Breedin (1992) reported patients who showed a phonological short-term memory deficit, yet did not show speech perception difficulties. Our data showed the opposite: the possibility that retaining information might interfere with perceptual processing.

Last, we mention KT's lesion. It was restricted to the left putamen, as we described, but the MR brain scan also showed dilatation of the left lateral ventricle. It is very

rare for a subcortical lesion to cause pure word deafness; however, Hamanaka et al. (Hamanaka, Asano, Morimune, & Seko, 1980) reported a patient with pure word deafness caused by a unilateral left subcortical lesion. Nadeau and Croson have discussed controversies about whether damage to the putamen can directly cause language disorders (Nadeau & Croson, 1997). It is not clear whether the language disorders discussed by Nadeau and Croson include speech perception disorders, and the lateralization for KT's disorders was not clear because the dilatation of the left lateral ventricle could have affected cortical function.

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