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Do Japanese speakers perceive nonexistent vowels in non-native consonant clusters?

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Vowel epenthesis is a well known phenomenon that non-native speakers insert epenthetic vowels inside non-native consonant clusters. Vowel epenthesis is assumed as perceptual "illusory vowels" (Dupoux et al. 1999). We analyzed vowel epenthesis shown by native Japanese speakers during reading and repetition tasks for non-native consonant clusters, and analyzed their brain responses using magnetoencephalographic methods. Under the reading task, in which subjects read English words and nonsense words, native Japanese speakers inserted vowel /o/ after /t/ and /d/ in consonant clusters, and vowel /u/ after other consonants. Under the repetition task, in which subjects repeated utterances of a native English speaker, native Japanese speakers did not produce epenthetic vowels, with a few exceptions. The length of exceptional epenthetic vowels found under the repetition task was shorter than those under the reading task. The magnetoencephalographic mismatch responses were elicited by epenthetic vowels, suggesting that the native Japanese detected epenthetic vowels as real segments. Based on these results, we conclude that vowel epenthesis by native Japanese speakers did not arise from "illusory vowels", but rather from the difficulty of articulating consonant clusters which are not found in Japanese, and/or Japanese phonological rules.

1 Introduction

It is well known that second language learners have difficulties in pronunciation of some phonemes which do not exist in their native languages. For instance, French nasal vowels are hard to pronounce correctly for Japanese learners. Some phonemes, even belonging to the native language, may be difficult to pronounce depending on the contexts which the phonotactics of the language do not allow the phoneme sequences. English speakers, for instance, pronounce “zg” and “zb” in Polish /zəg/ and /zəb/, respectively [1]. Japanese speakers often insert vowels in consonant clusters (e. g. English word “drama” may be pronounced as /dorama/), possibly because Japanese does not allow the consonant sequences due to its phonotactics.

Dupoux et al. reported that Japanese speakers perceive non-existent “illusory vowel /u/” in consonant clusters based on their phoneme detection tasks and ABX tests [2, 3]. Denaene-Lambertz et al. reported that using quasi-oddball paradigm (igmo vs. igumo) in electroencephalographic experiment they could not observe mismatch like pattern in Japanese subjects, but observed it in French subjects [4]. However, in the stimuli used in Dehaene-Lambertz’s study and Dupoux’s study, coarticulation with following vowels was not taken into account. They removed the vowel segment between the consonants to create the target consonant clusters. Therefore, some coarticulation effects from the deleted vowel segment might remain in the consonants, which may generate different timbres compared to the consonants articulated without the vowel segment.

Consonant sequences and closed syllables are not allowed in Japanese. Vowel epenthesis is frequently observed in loan words, and vowel /o/ is inserted after /t/ and /d/, vowel /i/ is inserted after /tʃ/ and /dʒ/, and vowel /u/ is inserted after other consonants [5]. The epenthetic vowels are chosen based on faithfulness constraints i. e. “faithfulness constraints require the correspondence between the input and output” [6, 7].

In this study, we investigated vowel epenthesis in Japanese in two aspects, production and perception. We carried out four experiments. Reading test 1 was done to confirm the aspects of vowel epenthesis of native Japanese speakers. A repetition test examined the relationship between perception and production. Reading test 2 confirmed the robustness of vowel epenthesis. Then a magnetoencephalographic test revealed the potential of the detection of epenthetic vowels in Japanese speakers.

2 Reading test 1

2.1 Method

The speech samples were English words which have a consonant cluster including /t/ or /d/ at the word initial position and non-words which have a consonant cluster at the word initial position. These target words and non-words written in Roman alphabet as shown in Table A were presented to 16 native Japanese female speakers to read aloud in a sound proof room. To verify the effects of words vs. non-words utterance order, the subjects were divided into two groups, A and B. Group A (8 subjects) read English words first and non-words next, Group B read in the reverse order. The utterances were recorded by a solid state recorder (Marantz PMD671) at an 11.025 kHz sampling rate. Epenthetic vowels and their lengths were measured by visual inspection of the spectrogram on a computer.

Table A

English word	drill	drama	drive	dress	dry	strike
	straight	stripe	trouble	truck	trend	try
Non-word	edmo	etmo	dra	tra	gra	cra
	bra	pra				

2.2 Results

Table 1 and 2 shows the result of the reading test 1. A~H and O~V indicate individual subjects. In most of the words and non-words, subjects inserted vowels in consonant clusters. However, in the case of /s/-/t/ in cluster /str/, no voiced vowel is observed. In /s/-/t/, vowel devoicing might occur [8]. Vowel /o/ was inserted after /t/ and /d/, whereas vowel /u/ was inserted after other stop consonants (/p/, /b/, /k/, /g/). There are not any significant differences between the results shown in Table 1 with Table 2, suggesting no significant effects of the utterance order, words vs. non-words. Table 3 shows the mean values of the pooled data of Table 1 and 2. Vowel /o/ length inserted in the consonant

cluster /tr/ was significantly shorter than that in the consonant cluster /dr/ ($p<0.0001$) and the /str/ ($p<0.0001$). Vowel length in the /dr/ did not significantly differ from that in the /str/ ($p=0.6046$). Figure 1 shows spectrograms of "straight". The spectrogram (a) is an utterance of a native speaker of American English and (b) is of a native Japanese subject E. As shown in Fig. 1 (b), no voiced vowel is observed between /s/ and /t/, while a vowel /o/ between /t/ and /r/ is observed. Figure 2 shows non-word "dra" and "gra". Vowel /o/ is observed between /d/ and /r/, whereas /u/ is inserted between /g/ and /r/. Namely, it is confirmed that vowel /o/ inserted after /t/ and /d/ and vowel /u/ inserted after the other stop consonants as many previous studies demonstrated.

	A	B	C	D	E	F	G	H	mean
drill	107	84	81	63	62	64	86	107	79.9
drama	52	55	53	48	55	21	52	56	52.2
drive	44	[u] 31	66	42	52	50	63	51	53.4
dress	66	74	57	59	39	44	49	82	58.6
dry	47	63	60	59	73	47	41	80	58.8
strike	36	40	58	45	60	63	68	60	57.2
straight	65	42	52	58	76	55	60	54	59.7
stripe	66	50	86	58	70	44	70	46	61.3
trouble	37	0	36	35	24	21	28	39	28.1
truck	29	32	49	40	24	21	39	56	35.3
trend	23	37	42	59	37	23	44	60	38.7
try	42	0	53	38	55	31	31	51	38.3
edmo	121	37	69	67	72	54	91	[u] 88	72.9
etmo	58	39	69	51	54	67	62	[u] 92	54.5
dra	89	78	63	83	55	99	62	73	76.9
tra	45	60	82	56	42	55	52	85	59.3
gra	79	74	57	58	41	140	49	80	71.2
cra	53	57	24	29	24	57	42	65	45.6
bra	73	105	47	63	73	65	47	63	71.7
pra	45	33	60	45	39	52	[a] 68	85	51.3

Table 1 Epenthetic vowel lengths in the reading test 1 (Group A). (ms)

Epenthetic vowels were inserted in underlined consonants. A-H indicate individual subjects. Subjects usually inserted /o/ in "drill"-"tra", while they inserted vowel /u/ in "gra"-"pra".

	O	P	Q	R	S	T	U	V	mean
drill	59	54	59	81	100	[u] 92	71	71	70.7
drama	92	55	36	60	74	[u] 37	[#] 56	39	59.3
drive	22	31	62	28	48	[u] 43	43	[u] 17	39.0
dress	[u] 31	38	69	62	64	[u] 54	[u] 27	51	56.8
dry	[u] 29	47	45	0	57	[u] 66	0	36	30.8
strike	36	48	33	83	66	[u] 44	53	37	50.9
straight	19	74	55	x	41	[u] 49	31	46	44.3
stripe	10	41	45	x	45	90	32	44	36.2
trouble	19	29	50	24	22	56	[#] 39	0	28.6
truck	16	43	54	22	33	[u] 34	46	29	34.7
trend	0	24	40	48	40	32	[u] 17	32	30.9
try	28	36	38	0	50	[u] 54	0	27	25.6
edmo	62	73	69	52	x	[u] 53	0	43	49.8
etmo	66	57	31	59	92	[u] 56	0	39	49.1
dra	[u] 21	88	52	88	[u] 129	[u] 72	34	49	62.2
tra	43	62	48	64	95	[u] 54	39	43	56.3
gra	35	120	55	83	158	70	20	26	70.9
cra	38	112	55	130	[a] 119	43	24	29	61.6
bra	60	71	57	62	119	77	66	27	67.4
pra	22	119	24	40	95	49	34	31	51.8

Table 2 Epenthetic vowel lengths in the reading test 1 (Group B). (ms)

O-V indicate individual subjects. X indicates pronunciation error. [#] = [ə]

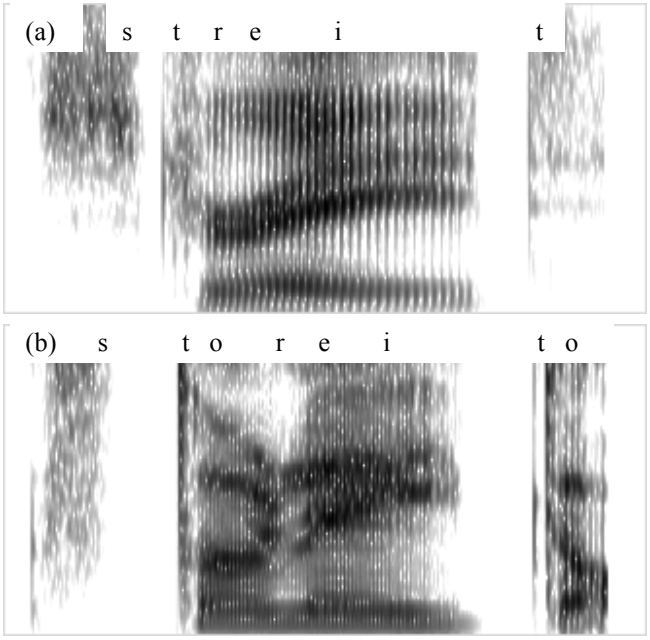

Figure 1 Spectrograms of "straight".
(a) a male speaker of native English, (b) subject E.

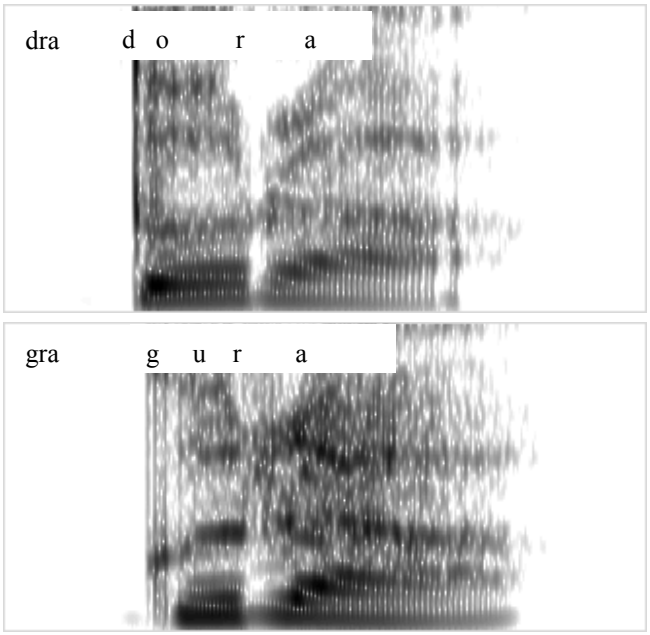

Figure 2 Spectrograms of "dra" and "gra" in subject D.

3 Repetition test

3.1 Method

The speech stimuli were English words and non-words used in the reading test 1 spoken by a male speaker of native American English. These utterances were recorded in a computer at an 11.025 kHz sampling rate. The subjects were Group A in the reading test 1. They were instructed to listen to one of these words and non-words through the headphone, and immediately repeat it three times as exactly as possible. Their utterances were recorded at an 11.025 kHz sampling rate by a solid state recorder (Marantz PMD671). The first utterances were measured in general, but the first utterance was not correctly pronounced (e. g.

"bra" was pronounced as /baa/), second or third one was measured. Epenthetic vowels if any and their lengths were measured by visual inspection of the spectrogram of the best utterance on a computer.

3.2 Results

The results were shown in Table 4. In most of the utterances, with few exceptions Japanese speakers did not produce epenthetic vowels in repetition test. Moreover, the length of exceptional epenthetic vowels found under the repetition test was shorter than those under the reading test 1. Figure 3 shows a spectrogram of "straight" of subject E. By comparison with a spectrogram of subject E in the reading test 1, Figure 1(b), no vowels were apparently observed in the consonant cluster /str/. Figure 4 shows the spectrograms of two subjects. In both subjects there are no vowels in consonant cluster /dm/ in non-word "edmo". If native Japanese speakers heard non-existent vowels in consonant clusters, they would insert vowels in consonant clusters in repetition test. In the repetition test, vowel epenthesis seldom occurred, therefore it is inferred that the native Japanese speakers did not hear non-existent vowels in consonant clusters.

	mean
drill	76.6
drama	53.4
drive	46.3
dress	58.0
dry	46.8
strike	52.4
straight	52.0
stripe	53.1
trouble	28.0
truck	35.5
trend	38.6
try	32.0
edmo	62.3
etmo	53.1
dra	70.2
tra	58.1
gra	71.6
cra	52.1
bra	67.2
pra	51.5

Table 3 Pooled data of the reading test 1.

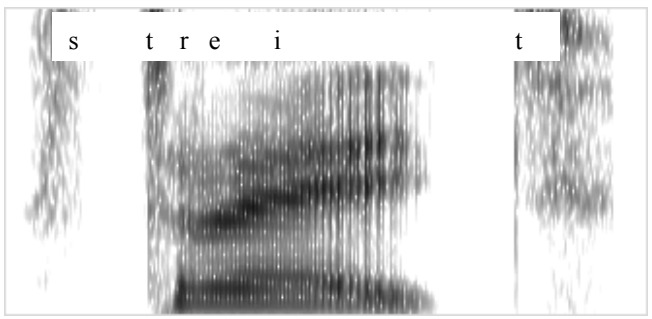

Figure 3 a spectrogram of "straight" spoken by subject E in repetition test.

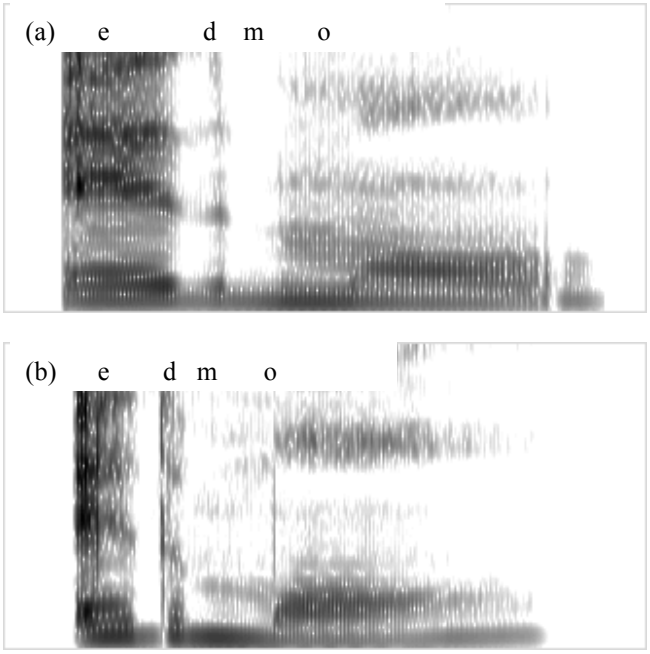

Figure 4 Spectrograms of "edmo" in repetition test. (a) subject B, (b) subject D.

	A	B	C	D	E	F	G	H
drill	0	0	0	0	0	0	0	[u] 58
drama	0	0	0	[o] 43	0	0	0	0
drive	x	0	0	0	0	0	0	[o] 30
dress	[o] 30	0	0	0	0	0	0	[o] 37
dry	0	0	0	0	0	0	0	[u] 43
strike	0	0	0	0	0	0	0	x
straight	[o] 22	0	0	0	0	0	0	0
stripe	[o] 15	[o] 20	x	0	0	0	[o] 30	0
trouble	0	0	0	0	0	0	0	0
truck	0	0	[o] 18	0	0	0	0	0
trend	0	0	0	0	0	0	0	0
try	0	0	0	0	0	0	0	[o] 40
edmo	0	0	0	0	0	0	0	[u] 43
etmo	0	0	[o] 43	0	[e] 30	0	0	0
dra	0	0	0	0	0	0	0	0
tra	0	0	0	0	0	0	x	0
gra	0	0	0	0	0	0	0	[u] 52
cra	0	0	0	0	0	x	0	0
bra	x	0	0	x	0	x	0	[u] 60
pra	x	0	0	x	0	x	x	x

Table 4 Epenthetic vowel lengths in repetition test. Subjects A~H correspond to Table 1.

4 Reading test 2

4.1 Method

Reading test 2 was done after 5 or 6 months after reading test 1. Subjects were Group A in the reading test 1. Speech samples and procedures were the same as for the reading test 1.

4.2 Results

Results are shown in Table 5. In comparison with Table 1, as in the case of the reading test 1, most of the subjects

inserted vowels in consonant clusters. Although subjects did not insert vowels in the repetition test, nevertheless they inserted vowels this time. Our subjects were novices at English conversation, not good at speaking English. Therefore, we might suppose that when they looked at an English word, they associated it with a corresponding loan word. Consequently, they might insert vowels in consonant clusters.

	A	B	C	D	E	F	G	H	mean
drill	104	76	85	82	63	[u] 19	83	138	90.1
drama	62	55	45	52	34	26	61	99	54.3
drive	37	53	48	42	39	[u] 19	56	63	48.3
dress	50	45	30	37	65	0	56	99	47.8
dry	40	47	35	49	61	46	46	77	50.1
strike	39	42	53	40	56	0	70	60	45.0
straight	50	43	50	38	61	25	68	62	49.6
stripe	57	52	x	38	70	0	56	x	45.5
trouble	50	22	0	26	58	0	63	25	30.5
truck	[*] 30	12	0	21	22	0	26	80	23.0
trend	[*] 45	18	0	28	27	0	54	43	24.3
try	44	37	25	33	17	15	54	43	33.5
edmo	74	58	55	57	49	66	44	[u] 95	57.6
etmo	74	0	74	49	63	53	60	[u] 90	53.3
dra	99	58	60	56	73	61	77	88	71.5
tra	70	0	70	42	66	[*] 43	66	106	60.0
gra	59	73	81	56	71	75	70	61	68.3
cra	28	0	60	35	44	31	53	56	38.4
bra	104	108	23	40	85	80	54	105	74.9
pra	54	0	35	45	36	48	53	76	43.4

Table 5 Epenthetic vowel lengths in the reading test 2.

Subjects A~H correspond to Table 1. [*] = [o̥]

5 Magnetoencephalographic test

5.1 Method

The subjects were native Japanese speakers. All subjects were right-handed, and had no hearing loss. Subjects were instructed not to attend to the stimuli and to hear passively to the stimulus sequence. Stimuli were binaurally presented to subjects by inserted earphones. Stimuli, /dra/, /dora/, /bra/, and /bura/ were spoken by a male speaker of Japanese. An oddball paradigm was adopted, in which a standard stimulus was presented at a high frequency of 85% and deviant at a low frequency of 15%. Deviants never occurred in immediate succession. Stimulus onset asynchrony was one second. Four sessions with a standard-deviant pair set as /dra/ vs. /dora/, /dora/ vs. /dra/, /bra/ vs. /bura/ and /bura/ vs. /bra/, respectively, were conducted in a counter-balanced order. The recordings were performed in a magnetically shielded room using a 204-channel whole head magnetometer (Neuromag Ltd., Finland). Mismatch fields (MMF), which is an event-related neural response reflecting automatic detection of acoustic changes, were analyzed. MMF was determined from the deviant stimulus response minus the standard stimulus response subtraction waves. For each subject and condition, equivalent current dipoles (ECDs) were determined for the MMF.

5.2 Results

Figure 5 shows a magnetic field of /dora/ deviant in one subject and distinct MMF is observed. Figure 6 shows the ECD moment in dr (/dra/ vs. /dora/ and /dora/ vs. /dra/) and br (/bra/ vs. /bura/ and /bura/ vs. /bra/) conditions. In all conditions MMFs were generated, hence it is apparent that subjects detected vowel insertion in consonant clusters.

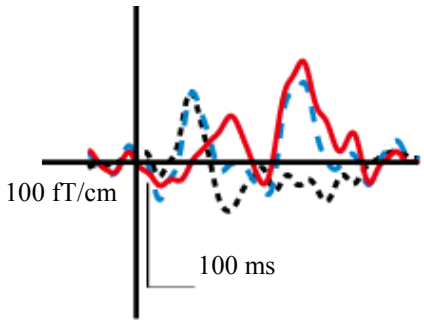

Figure 5 Magnetic fields of deviant “dora”.

Red line: MMF, blue dashed line: deviant stimulus response, black dotted line: standard stimulus response.

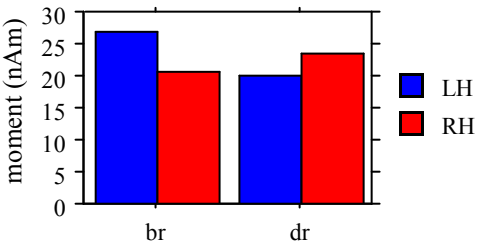

Figure 6 ECD moments.

LH: left hemisphere, RH: right hemisphere.

6 Discussion

In the reading test, the native Japanese speakers inserted a vowel in the consonant clusters as required in Japanese phonotactics, whereas in the repetition test, they did not insert any vowel in the consonant clusters with few exceptions. Moreover, the exceptionally inserted vowels in the repetition test were shorter than those in the reading test 1. If they perceived a non-existent vowel in the consonant clusters, they would insert a vowel in the consonant clusters even in the repetition test. Moreover, the lengths of the inserted vowels would be the same as those in the reading test 1. The magnetoencephalographic test showed that since apparent MMFs were generated, epenthetic vowels in consonant clusters were detected by Japanese subjects. According to the above results, we interpret our results that native Japanese speakers can detect epenthetic vowels in consonant clusters and can correctly pronounce consonant clusters, but their detection sensitivity for a vowel segment in a consonant cluster may be lower than French subjects. When Japanese subjects read loan words, they tend to insert a vowel in consonant clusters following the phonological constraints of Japanese which do not allow consonant clusters. Japanese speakers need to perceive the same words whether a vowel exists in a consonant cluster or not. The sensitivity of Japanese speakers to detect vowel deletion or

insertion within a consonant cluster does not decline at least at the acoustical level, but is suppressed at the word recognition level following the phonological constraints of Japanese.

7 Conclusion

The results of the present study suggest that native Japanese speakers can detect epenthetic vowels in consonant clusters and can correctly pronounce consonant clusters. The sensitivity of Japanese speakers to detect vowel deletion or insertion within a consonant cluster does not decline at least at the acoustic perceptual level, but seems to be suppressed at the word recognition level to follow the phonological constraints of Japanese.

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