

# THE EFFECT OF CONSONANTAL CONTEXT AND ACOUSTIC CHARACTERISTICS ON THE DISCRIMINATION BETWEEN THE ENGLISH VOWEL /ʌ/ AND /ɒ/ BY JAPANESE LEARNERS

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## ABSTRACT

This paper investigated how Japanese learners of English discriminated the American English vowel /ʌ/ from /ɒ/ in /CVt/ monosyllables with 23 different initial consonants, and how the differing discrimination was related to the acoustic characteristics of the English vowels compared with those of Japanese vowels /i/ and /e/ in disyllables with a final syllable of /to/. The results showed that the overall error rate of /ʌ/ was significantly higher than that of /ɒ/. This difference between the two vowels in discrimination could be accounted for by the acoustically closer relations of /ʌ/ to the Japanese vowel /e/. It was found, however, that the discrimination of the two English vowels varied across the consonantal contexts. The error rate was significantly higher when the initial consonant was /t, d, s/ or /j/ for /ʌ/ and when it was /r/ for /ɒ/. An acoustical analysis indicated that the greater decrease of the ratio of the F2 frequency to the F1 frequency of /ʌ/ through the vowel, rather than the acoustical closeness of /ʌ/ to the Japanese /e/, tended to be more closely related with the poorer discrimination of this vowel in the particular consonantal contexts.

## 1. INTRODUCTION

Some pairs of English sounds are more difficult, and some are easier for Japanese listeners to differentiate. It is known that the English vowel /ʌ/ has the quality between the Japanese vowel /i/ and /e/, and it is, therefore, predicted that Japanese learners of English would have difficulty in discriminating /ʌ/ from /ɒ/, which is considered to be similar to the Japanese /e/ in quality. Strange et al. (1998) reported that the English vowel /ʌ/ was perceptually most often assimilated to the Japanese /i/, and /ɒ/, to /e/. They predicted, on the basis of the results of their experiments, that /ʌ/ and /ɒ/ would be differentiated with greater ease by Japanese learners of English because they constitute 'Two-Category assimilation pattern' according to Perceptual Assimilation Model proposed by Best (1995), which predicts perceptual difficulties in discriminating non-native segmental contrasts on the basis of patterns of perceptual assimilation of second language segments to native language categories. During the past years of investigation of these two English vowels in various consonantal contexts, however, Joto (1987, 1988, 1999) has found that there was a significant difference between the discrimination of /ʌ/ and that of /ɒ/ by Japanese learners and that it varied from consonantal context to context. This paper attempts to verify the prediction by Strange et al. and Best's PAM model and to account for variability in the perceptual differentiation from the acoustical point of view.

The aims of this study are to examine how Japanese learners discriminate /ʌ/ from /ɒ/ in various consonantal contexts where the final consonant is /t/, and to investigate how the differing discrimination is related to the acoustic characteristics of the

vowels in comparison with those of Japanese vowels /i/ and /e/ to find out which acoustic factors have the most effect on the differing discrimination. Two kinds of experiments were conducted to clarify the problem: the first experiment was a perceptual test to examine how differently Japanese speakers of English discriminated between the English two vowels in different consonantal contexts, and the second one was an acoustical analysis of the English and Japanese vowels to investigate the relation between the differing vowel discrimination and the acoustic characteristics of the vowels in various consonantal contexts.

## 2. EXPERIMENT 1

### 2.1. Stimulus Materials

Three male native speakers of American English produced the stimulus corpus. They were all the speakers of General American and ranged in age from 24 to 36 years old. Each speaker produced a total of 138 randomly ordered English words which were meaningful or nonsense. They composed 23 sets of monosyllabic word pairs containing the vowel /ʌ/ or /ɒ/ in the context of 23 different initial English consonants and the final consonant of /p/, /t/ or /k/. Each speaker was recorded in an anechoic chamber, using a dynamic microphone connected to a DAT recorder. These words were sampled at 10kHz and transferred to computer files. The 138 words of each speaker's production were randomly ordered on a computer, and were converted to analog signals to be transferred into audio cassette tapes for the experiment.

### 2.2. Listeners

Twenty-three female Japanese university freshmen (18 or 19 years old) participated in the perceptual test. All of them were phonetically naïve. All the participants had received 6 years of English classes in junior and senior high schools in Japan. None of them were speakers of Tokyo dialect which is recognized as standard Japanese. None of the listeners had any experience of living in another country for six months or more, or received education at any schools where instruction was done only in English.

### 2.3. Procedures

Prior to the test, listeners received instructions in Japanese. They listened to 3 sets of 138 words through loudspeakers in a language laboratory with a short break between sets. The stimuli were presented to the listeners once in random order at 2 second interstimulus intervals. They circled the word they heard on the answer sheets where 138 sets of word pairs per set of production were printed in alphabet letters.

In order to limit the words to be examined in this study to only

those which native speakers of English can discriminate, the same test was performed with 5 native speakers of American English in the same language laboratory using the same procedure as that of the test for the Japanese learners. They were four males and one female who were all teachers of English in Japan.

## 2.4. Results

Because of the page limitation of this paper, the author limited the English words to be examined and discussed to only the words with a final consonant of /t/ where the most conspicuous differences in discrimination were seen across the consonantal contexts. Therefore, a total of 138 words were employed: 2 vowels×23 consonants×3 speakers.

initial consonant	error rate (%)	initial consonant	error rate (%)
ɛr	87.0	□	15.9
ɸ	42.0	dʌ	11.6
ʋ	33.3	ɹ	11.6
ʒ	24.6	●	10.1
ʊ	23.2	±	8.7
dʌ	23.2	ʌ	8.7
ɹ	20.3	ɹ	7.2
ʋ	20.3	●	5.8
ʒ	18.8	ɹ	4.3
ʊ	18.8	●	4.3
ɸ	18.8	ʊ	2.9
ɹ	17.4	□	2.9
ɸ	17.4	□	2.9
ɹ	15.9	s	2.9
ʋ	14.5	ʋ	2.9
ʌ	11.6	ʌ	1.4
ʌ	11.6	ʌ	1.4
●	10.1	ɹ	1.4
ɹ	5.8	ʋ	1.4
ɹ	5.8	ʋ	1.4
ʌ	5.8	●	0.0
ʌ	4.3	ɸ	0.0
ɸ	4.3	ɛr	0.0
high error	54.1	high error	15.9
low error	7.5	low error	0.9
mean	19.8	mean	4.8

**Table 1:** Error rates of /ʌ/ in different consonantal contexts. **Table 2:** Error rates of /ɹ/ in different consonantal contexts.

It was found from the results of the perceptual test for the native speakers of English that almost all the words were correctly discriminated. Exceptions were /jʌ/ and /ɸʌ/. In both cases, only one out of five subjects did not discriminate correctly. This does not mean that they should be eliminated from the word corpus as the objects of the study because they are inadequate stimuli for the Japanese learners to discriminate. Therefore, all the 23 sets of word pairs, each of which the three speakers produced, (138 words in total) were employed for examination and analysis in this study.

The results presented in table 1 and 2 indicated that the overall error rate of /ʌ/ (19.8%) was significantly higher than that of /ɹ/

(4.8%) ( $\chi^2$ -test:  $p < 0.01$ ). On the whole, therefore, the Japanese learners more often misheard /ʌ/ for /ɹ/. However, the discrimination of /ʌ/ and /ɹ/ differed across the consonantal contexts. The chi-square test showed that the error rate was significantly higher when the initial consonant was /tʌ/, /ɸʌ/ or /jʌ/ for /ʌ/ (mean of error rates: 54.1%) and /ɹ/ (15.9%) for /ɹ/ (henceforth, high error group), while it was significantly lower when the initial consonant was /bʌ/, /hʌ/, /kʌ/, /lʌ/ or /vʌ/ (mean of error rates: 5.2%) for /ʌ/ and /hʌ/, /kʌ/, /lʌ/, /tʌ/, /ɸʌ/, /ɹʌ/, /jʌ/ or /zʌ/ (mean of error rate: 0.9%) for /ɹ/ (hereafter, low error group) ( $p < 0.05$ ).

## 3. EXPERIMENT 2

### 3.1. Speech Materials

An acoustical analysis was performed on the English vowels, /ʌ/ and /ɹ/ and the Japanese vowels, /i/ and /e/ in different consonantal contexts, to each of which /ʌ/ and /ɹ/ were respectively perceptually most similar (Strange et al., 1998). The English speech materials were the same as used for the experiment 1 which had a final consonant of /t/. The Japanese speech materials were the disyllabic / tri-moraic meaningful and nonsense words containing /i/ or /e/ with a final syllable of /to/ because a consonant followed by a vowel is the basic sound unit in Japanese. The phonetically equivalent Japanese words to English monosyllabic words with a checked vowel and a final stop consonant are of three moras, /C<sub>1</sub>V<sub>1</sub> C<sub>2</sub>V<sub>2</sub>/ (/C<sub>1</sub>V<sub>1</sub>C<sub>2</sub>V<sub>2</sub>/) where the Japanese language counts a glottal stop (or the first C<sub>2</sub>) as one mora, because an English closed syllable sounds like a glottal stop plus a plosive consonant (followed by a vowel, as described above) to Japanese ears: for example, /bʌ/ is phonetically translated as /bʌto/ (/bitto/) in Japanese pronunciation. Some initial consonants do not have parallel sounds in the two languages. Therefore, the number of initial consonants in Japanese words was 15 ([b, ɸ, ɹ, ʌ, ɹ, ʌ, ɹ, ʌ, ɹ, ʌ, ɹ, ʌ, ɹ, ʌ, ɹ] 5 4 7 /ʌ/ and 17 ([ɸ, ɹ, ʌ, ɹ, ʌ, ɹ, ʌ, ɹ, ʌ, ɹ, ʌ, ɹ, ʌ, ɹ, ʌ, ɹ, ʌ, ɹ] 3 5 ɸ 8 9 ɹ 35)) for /ɹ/. The Japanese words were produced by three male native speakers of Japanese. The speakers were all undergraduate university students, whose ages ranged from 21 to 24 years old. Each of them spent his school days (elementary and junior high school) in a different region in Japan: Hyogo, Nagasaki or Hiroshima, where standard Japanese is not spoken in terms of word accent, but basically no difference in sound segments are recognized to exist. For the recording, they were instructed to produce each word with an accent on the first syllable.

### 3.2. Method

The English and Japanese vowels in each different consonantal context were acoustically analyzed by computer. Analyses were conducted on a NEC PC-9801 NS/A, using "Onsei Rokubunken" speech analysis software v. 5 developed by H. Imagawa and S. Kiritani at the University of Tokyo. The acoustic factors to be analyzed were the first and second formant frequencies of the vowels. Formant values were measured on the display of LPC formant tracks superimposed on the wideband spectrograms. In order to examine the temporal change of formant frequencies, F1 and F2 frequencies were measured at the temporal locations, 25%, 50% and 75%, through the vowel portion of each word. A 6.4 hamming window was used for the measurement of formant frequencies at each temporal location. The ratios of the second formant frequency to the first formant frequency (henceforth, formant ratio) at each temporal location were calculated on the

basis of the measurements of formant frequencies of the vowels.

### 3.3. Results

It is a general notion that /ʌ/ has lower F1 frequency and higher F2 frequency than /ɛ/. In other words, the formant ratio of /ʌ/ is bigger than that of /ɛ/. Table 3 and 4 showed that on the whole, as in the general notion, the formant ratio of /ʌ/ was bigger than that of /ɛ/ at each temporal point. It was found that the greatness order of the mean formant ratio was /i/ > /ʌ/ > /e/ > /ɛ/ at the 25% and 50% points, and that at the 75% point it was /i/ > /e/ > /ʌ/ > /ɛ/. This order stayed the same both in the high error group and in the low error group. Therefore, acoustically, /ʌ/ is more closely related to /e/ in the former half of the vowel and to /ɛ/ in the latter part of the vowel.

**Table 3:** Formant ratios of /ʌ/ and /ɛ/ in the high and low error

initial consonant	/i/			/ɛ/		
	25%	50%	75%	25%	50%	75%
high error	4.57	4.09	3.81	2.72	2.70	2.79
low error	4.09	3.96	3.93	3.00	2.78	2.79
mean	4.17	3.97	3.86	3.07	2.82	2.78

groups at each temporal location.

**Table 4:** Formant ratios of /i/ and /e/ at each temporal location.

vowel	temporal location		
	25%	50%	75%
/i/	7.25	7.40	7.78
/e/	3.84	3.80	4.15

Which vowel does /ʌ/ have a more closer relation with, then? The difference of the mean formant ratios between /ʌ/ and each of the other three vowels was calculated at each temporal location: it was 3.08, 3.43, 3.92 between /ʌ/ and /i/, 1.1, 1.15, 1.08 between /ʌ/ and /ɛ/, and 0.33, 0.17, 0.29 between /ʌ/ and /e/ respectively at each temporal location. This indicates that /ʌ/ had the acoustically closest relation with /e/ throughout the vowel. The acoustic relation between /ʌ/ and /e/ was closer than that between /ɛ/ and /e/: the difference of the formant ratios between /ɛ/ and /e/ was respectively 0.77, 0.98, 1.37 at each temporal location. Therefore, we could say that /ʌ/ was more similar to the Japanese /e/ in quality.

Next, we will examine what acoustic differences existed between the high error groups and the low error groups of /ʌ/ and /ɛ/. Table 3 showed that the formant ratio of /ʌ/ was bigger in the high error group than in the low error group at the 25% and 50% locations, but that at the 75% point it was smaller in the high error group than in the low error one. The difference of the formant ratios at each temporal location between /ʌ/ of the high error group and /e/ (mean) was bigger than that between /ʌ/ of the low error group and /e/ (mean): the difference was 0.73, 0.29, 0.34 respectively at each temporal point in the high error group, and 0.29, 0.22, 0.19 in the low error one. It indicates that /ʌ/ of the low error group was acoustically closer to /e/ than that of the high error group. As presented in Table 3, however, the formant ratio of /ɛ/ was smaller in the high error group than in the low error one at the 25% and 50% points, but it was the same at the 75% point. This demonstrates that the former part of /ɛ/ was closer to /e/ in the low error group than in the high error one, and that the latter part of /ɛ/ in both the high and low error groups was closer to /ʌ/ than any other vowel. However, the former part of /ɛ/ was also

closer to /ʌ/ in the low error group than in the high error one: the difference of the formant ratios between /ɛ/ of the high error group and /ʌ/ (mean) was respectively 1.45, 1.27, 1.07, and that between /ɛ/ of the low error group and /ʌ/ (mean) was respectively 1.17, 1.19, 1.07 at each temporal location. The formant ratios of /ɛ/ of the high error group were the smallest in those of all the vowels, and therefore, the acoustical relationship between /ɛ/ of the high error group and the other vowels was the most distant one.

## 4. DISCUSSION

As stated in Introduction, Strange et al. (1998) predicted that /ʌ/ and /ɛ/ would be differentiated with greater ease by Japanese learners. Experiment 1 showed that the Japanese learners discriminated between /ʌ/ and /ɛ/ with more than 80% correctness, and we could say this pair, /ʌ/ < /ɛ/, was one of the vowel pairs which can be fairly accurately discriminated by Japanese learners. Since we did not examine the other pairs in this study, we could not say whether this pair was easier to discriminate or not. We found, however, that there was a significant difference in discrimination between these two vowels: the overall discrimination of /ɛ/ was better than that of /ʌ/. The results of acoustical analysis could account for this difference. As examined in the previous section, acoustically, /ʌ/ was more closely related to the Japanese /e/ throughout the vowel, and /ɛ/, to /e/ in the 25% and 50% temporal locations. And /ʌ/ had a closer relation with /e/ than /ɛ/ did. It could be considered that the better discrimination of /ɛ/ than that of /ʌ/ could be attributed to the acoustic closeness of /ɛ/ to /e/ in the former half of the vowel, but that the much closer relation of /ʌ/ with /e/ which /ɛ/ was most often assimilated to could affect the poorer discrimination of /ʌ/.

The acoustic closeness or similarity between the vowels, however, was not a factor which affected the differing discrimination of /ʌ/ and /ɛ/ across the consonantal contexts, because /ʌ/ was closer to /e/ in the low error group than in the high error one, and because /ɛ/ was not closer to /ʌ/ nor to /i/ in the high error group than in the low error one. Therefore, we need to ask what factor would affect the differences across the consonantal contexts.

In Table 3, the formant ratio of /ʌ/ was bigger at the 25% and 50% points but smaller at the 75% point in the high error group than in the low error group. This means that the difference of the formant ratio between the 25% and the 75% point was bigger in the high error group than in the low error one. So the difference of the formant ratios of /ʌ/ and /ɛ/ between each temporal location was calculated as in the Table 5.

initial consonant	/i/			/ɛ/		
	25-50%	50-75%	25-75%	25-50%	50-75%	25-75%
high error	-0.48	-0.28	-0.76	-0.02	0.09	0.07
low error	-0.13	-0.03	-0.16	-0.21	0.01	-0.20
mean	-0.20	-0.11	-0.31	-0.25	-0.03	-0.29

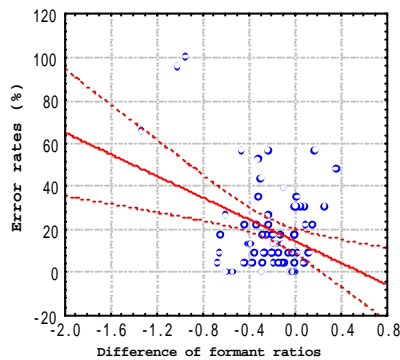
**Table 5:** Difference of the formant ratios of /ʌ/ and /ɛ/ between temporal locations. Negative numbers indicate the decrease of the formant ratios in a vowel part between temporal locations.

As presented in Table 5, the difference of the formant ratio of /ʌ/ was bigger in the high error group than in the low error one in all the three parts of the vowel: the former part (25%-50%), the latter part (50%-75%) and the whole vowel part (25%-75%). All the numbers were negative. This means that in the high error group the formant ratio of /ʌ/ decreased more greatly through the vowel

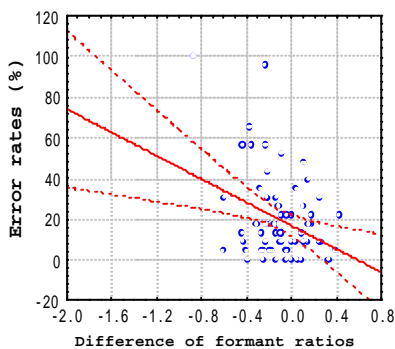
than in the low error one.

For closer examination on the relation of the differing discrimination to the acoustical data, correlation was measured between the error rates and the difference of the formant ratio of /ʌ/ in each vowel part. Figure 1, 2 and 3 indicated that a negative correlation was stronger in the whole vowel part ( $r=-0.42$ ) than in the former part ( $r=-0.35$ ) and the latter part ( $r=-0.33$ ). This demonstrates that the variability in the discrimination of /ʌ/ across the consonantal contexts tended to be more closely related to the greater decrease of the formant ratio throughout the vowel than the acoustical closeness of /ʌ/ to /e/. It could be suggested from this result that this greater change of formant patterns in which the formant pattern of /ʌ/ became closer to the that of /e/ toward the end of the vowel could affect the poorer discrimination of this vowel in the specific consonantal contexts by the Japanese learners.

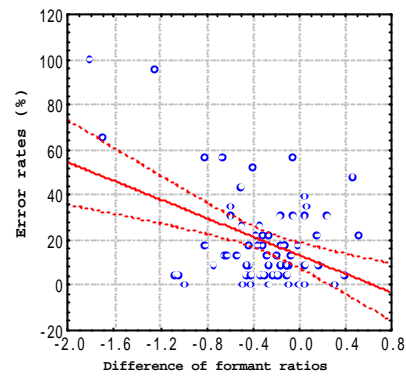
As for /ɛ/, there was no correlation between the error rates and the difference of the formant ratios at each vowel part:  $r=0.02$  between 25% and 50%,  $r=-0.06$  between 50% and 75%, and  $r=-0.01$  between 25% and 75%. In our study we could not specify any of the acoustic factors examined here which might be considered as affecting the differing discrimination of this vowel across the consonantal contexts.



**Figure 1:** Correlation between the error rates of /ʌ/ and the difference of the formant ratios between 25% and 50% point. ( $r=-0.35$ )



**Figure 2:** Correlation between the error rates of /ʌ/ and the difference of the formant ratios between 50% and 75% point. ( $r=-0.33$ )



**Figure 3:** Correlation between the error rates of /ʌ/ and the difference of the formant ratios between 25% and 75% point. ( $r=-0.42$ )

## 5. CONCLUSION

It was found that there was a significant difference in their discrimination across the consonantal contexts. The acoustical analysis suggested that rather than the acoustically closer relation of /ʌ/ to /e/, the greater decrease of the formant ratio through the vowel /ʌ/ could have more effect on the poorer discrimination of this vowel in the particular consonantal contexts by the Japanese learners. There could not be found any specific acoustic characteristics of /ʌ/ which were related to the differing discrimination in the consonantal contexts.

Statistically speaking, the correlation between the error rates and the whole vowel part of /ʌ/ was not considered to be a strong enough one. Further study would be needed for statistically clearer findings using the larger samples of data of vowel productions by many more native speakers of English.

## 6. REFERENCES

- Best, C. T. "A Direct Realist View of Cross-Language Speech Perception," *Speech Perception and Linguistic Experience: Issues in Cross-Language Research*, edited by W. Strange, pp. 171-204, York Press, Baltimore, 1995.
- Joto, A. "Nihonjin gakushuusha no shiin-myakuraku ni yoru eigo-boin /ʌ/ no shikibetsu-ryoku (The Discrimination of the English Vowel /ʌ/ in Consonantal Context by Japanese Learners)," *Onsei-gakkai Kaihoo (The Bulletin of the Phonetic Society of Japan)*, No. 186, pp. 15-18, 1987.
- Joto, A. "Nihonjin gakushuusha no shiin-myakuraku ni yoru eigo-boin shikibetsu-ryoku --/ʌ/ ni tsuite-- (The Discrimination of the English Vowel /ʌ/ in Consonantal Context by Japanese Learners)," *Persica*, No. 15, pp. 1-10, 1988.
- Joto, A. "Eigo-boin shikibetsu eno shiin-myakuraku no eikyoo--CVC onsetsu ni okeru /ʌ/ to /ɛ/ ni tsuite-- (The Effect of Consonantal Context on the Discrimination of English Vowels --/ʌ/ and /ɛ/ in /CVC/ monosyllables--)," *Persica*, No. 26, pp. 119-128, 1999.
- Strange, W., Akahane-Yamada, R., Kubo, R., Trent, S. A., Nishi, K., and Jenkins, J. J. "Perceptual assimilation of American English vowels by Japanese listeners," *Journal of Phonetics* 26, pp. 311-344, 1998