The Smaller and Greater English Vowel Spaces of Japanese Speakers

Kaoru Tomita, Yamagata University,

Jun Yamada, Hiroshima University,

and

Shigenobu Takatsuka, Okayama University

Abstract

This study investigated how Japanese-speaking learners of English pronounce the three point vowels /i/, /u/, and /ɑ/ appearing in the first and second monosyllabic words of noun phrases, and the schwa /ə/ appearing in disyllabic words. First and second formant (F1 and F2) values were measured for four Japanese speakers and two American English speakers. The hypothesis that the area encompassed by the point vowels in the F1/F2 vowel space tends to be smaller for the Japanese speakers than for the English speakers was verified. The hypothesis that the area formed by the three schwas in *chicken*, *spoonful*, and *Tarzan* is *greater* for the Japanese speakers than for the English speakers and its related hypothesis were largely upheld. Implications for further research are briefly discussed.

Introduction

A standard textbook of Japanese-English phonetics and phonology states that Japanese vowels are relatively more centralized in a vowel chart as compared to English vowels (e.g., Homma, 1992; Ito, 1987; Matsui, 1996). It is said, for example, that the Japanese low vowels /a/ and /o/ are higher than their English counterparts /ɑ/ and /o/ while the Japanese back vowel /u/ is more fronted than English /u/ and /ʊ/. These phonologically different patterns between English and Japanese invite several questions as to Japanese speakers learning English. For example, one may ask to what extent Japanese speakers' /ɑ/ in *car* is different from English speakers' in terms of acoustic properties such as first and second formant (F1 and F2) frequencies.

To our knowledge, however, this and other related questions have not thus far been addressed. In the current study, we first examined the hypothesis concerning the English point vowels.

(1) The smaller point-vowel space hypothesis: The triangle area encompassed by the three English point vowels /i/, /u/, and /ɑ/ in the F1/F2 vowel space is smaller for Japanese speakers learning English as a second language than for native English speakers.

This hypothesis is based on two assumptions. First, the effect of L1 (Language One) interference is so potent that the English vowel space of Japanese learners at the intermediate level of English becomes smaller. This assumption, however, must empirically be tested. The second assumption is that the English point vowels are most spread out in the vowel F1-F2 space when they are accented in clear speech. In other words, the difference in vowel space between English speakers and Japanese speakers of English would become great when the accented point vowels are produced in clear speech, e.g., in citation form. On this assumption, we use an experimental task in which subjects produce words and phrases in citation form.

We note also that the spectral characteristics may vary substantially due to coarticulatiory effects depending on specific phonological environments. For example, the /i/ in *tea spoon* may not be the same as /i/ in *true peace* if the /i/ in the first case provides anticipatory front-back information about the following vowel /u/ in *spoon* (cf. Alfonso & Baer, 1982). That is, the F2 value of the /i/ in *tea* may be lower than that of the /i/ in *peace*. Note also that the distance between /i/ and /u/ for *tea spoon* may turn out to be approximately the same as that between /u/ and /i/ for *true peace* if the F2 value of the /u/ in *true* gets greater to the same extent as the F2 value of the /i/ in *tea* gets smaller. Given these possibilities, we need to select and compare point vowels in two phrases such as *tea spoon* and *true peace*.

An equally intriguing issue concerning Japanese speakers' vowel space in English is the issue of the vowel space formed by schwas or schwa-like vowels, which do not exist as such in Japanese. The nonexistence of the schwa naturally leads the Japanese speaker to substitute one of the five Japanese vowels /i, u, a, o, e/ for it in various linguistic environments. Some English loanword in Japanese attests to this linguistic phenomenon; for example, the first and second vowels in loanwords or loanword-like words such as *chicken*, *spoonful*, and *Tarzan* are similarly pronounced, i.e., /ʧikin/, /spu:nful/, and /ta:zan/, respectively. An empirical question here is whether Japanese speakers at an intermediate level of English have acquired the English-like schwa /ə/. The following hypotheses are formulated from this question.

(2) The greater schwa-space hypothesis: The schwa triangle area formed by *chicken, Tarzan*, and *spoonful* in the F1/F2 space is *greater* for Japanese speakers than for native English speakers.

(3) The shorter vowel-distance hypothesis: The first and second vowels in word such as *chicken* and *Tarzan* are the same or similar for Japanese speakers, so that the distances between theses vowels in words are shorter for Japanese speakers than for native English speakers.

Two previous studies are relevant to these hypotheses. One is Kondo (2000), in which advanced- and intermediate-level Japanese speakers of English were asked to read English sentences which included an unstressed form of the indefinite article *a*.

The results revealed that the intermediate-level learners' schwas varied greatly in F2, indicating that some were characterized as low vowels, whereas the advanced-level speakers' were by and large native-like. However, Kondo failed to point out that at least some tokens of the schwa that those intermediate-level speakers produced were also native-like in terms of both F1 and F2 values (see Figure 2.1, p. 34).

The other study of relevance to our study was conducted by Lee, Guion, and Harada (2006). These researchers found that late Japanese-English bilinguals produced English schwas which were more dispersed in the vowel space than native English speakers and early Japanese-English bilinguals, thereby showing that the mean distance between the schwas in words such as *introduce* and *kangaroo* in the vowel space was longer for the late Japanese-English bilinguals than for the latter two groups. In this regard, our study may be taken as a replication study using less proficient Japanese-English bilinguals, but we would, in addition, attempt to ascertain whether these hypotheses are tenable in all word contexts. Just like Kondo (2000), Lee *et al*. (2006) indicated only a general tendency for less fluent Japanese English learners to expand the English schwa. Although the F1 and F2 values of the 'idealized' schwa may be 500 Hz and 1,500 Hz (e.g., Lieberman & Blumstein, 1988, p. 37), several studies suggest that coarticulatiory effects are so great that the schwa is viewed as a vowel with no articulatory target position or a vowel having no acoustic identity of its own (e.g., Browman & Goldstein, 1992, cf. van Bergem, 1994). In this study, we wanted to learn more about F1 and F2 values of the schwa in various linguistic environments

Method

Subjects

One female and one male speaker of American English (hereafter FE and ME) and two female and two male Japanese speakers (FJ1, FJ2, MJ1, and MJ2) served as subjects. The native English speakers aged xx and xx years were both from Texas and had a minimum of 18 years experience as English teachers at the college level in

Japan. The four Japanese speakers who were from Northern or Central Japan were college students and their ages ranged from 19 to 23 years. The TOEIC® scores were 645, 755, 495, and 750 points for FJ1, FJ2, MJ1, and MJ2, respectively, and they were regarded as intermediate-level learners of college English.

Stimuli

The stimuli consisted of three pairs of noun phrases and five disyllabic words. The phrase stimuli were (1) *tea spoon* (/i-u/) and *true peace* (/u-i/), (2) *car user* (/a-u/) and *blue car* (/u-a/), and (3) *Far east* (/a-i/) and *peace march* (/i-a/). Each stimulus item was printed in a carrier phrase "the ____________" on a x cm × x cm sheet of paper.

The disyllabic words were (1) *spoonful*, (2) *chicken*, (3) *Tarzan*, (4) *redden*, and (5) *common*. While the words *chicken*, *Tarzan*, and *common* are used as English loanwords in everyday Japanese, the words *spoonful* and *redden* are not loanwords but *spoon* and *red* are. As stated in the Introduction, the second vowels in these words may be pronounced in the same manner as the first vowels in the same words. But one exception may be *redden* due to the possible effects of English words that Japanese learners are likely to learn in early stages of English language learning. There seem to be two sets of words in which the <-den> and /-den/ association competes with the <-den> and /-dun/ or /-don/ association in the learners' mental lexicons. The first set includes words such as *garden* (pronounced /ga:den/ by Japanese learners of English) and *Sweden* (/swe:den/), and the second includes words such as *sudden* (/sadun/ or /sadon/) and *widen* (/waidun/). If the effect of the second set wins out, the distance between the vowels in *redden* would be longer than those for the other words.

Each word item was printed in isolation on a x cm × x cm sheet of paper.

Procedure

Each speaker was presented with each test sheet and asked to clearly produce each test item 10 times. Each was instructed to pronounce each word as clearly as possible. This instruction was important particularly for native English speakers because schwa elision in conversational speech is not uncommon.

Recordings were made of 110 items (6 speakers × 11 items × 10 times) per subject using a Sony unidirectional dynamic microphone (F-V640) and a Marantz solid state recorder (PMD670) in a sound treated room. The microphone was positioned at a lip-to-mouth distance of approximately five cm.

Acoustic measurements

The speech samples were analyzed using the Praat speech analyzing software (http: www.praat.org). The sampling rate was 44.1 kHz with a 16 bit resolution. For each vowel, an attempt was made to select some duration of the steady-state segment, and the mean F1 and F2 values were used for analysis. The durations ranged from xx to xx msec.

Measurements could be difficult especially when we missed one of the formants. To avoid missing formants, we used example formant data from previous studies (Hillenbrand, Getty, Clark, & Wheeler, 1995; Labov, Ash, & Boberh, 2006) as a guide to where we should expect the target formats to occur.

Analysis

F1 and F2 values were compared between same gender subjects but not between female and male subjects. This was done because gender effects on acoustic properties could be far greater than the factors considered in this study (see Hillenbrand *et al.*, 1995; Huber *et al.*, 1999). An analysis of variance (ANOVA) with repeated measures was a basic tool used for mean comparisons.

Results

Point vowels

The mean F1 and F2 values of the point vowels appearing in first and second word positions in the experimental phrases for each subject in the female and male groups are shown in Tables 1 and 2.

TABLES 1 AND 2 GO ABOUT HERE

A 2 × 3 ANOVA with two word positions and three speakers was performed to examine the speaker effect in each gender. The patterns of results appeared similar between the female and male speakers, and we will describe the major results of the female speakers and add those of the male speakers, if informative.

For /i/, the F1 values in the first word position were significantly lower for the English speaker than for the Japanese speakers (see Table 1), thereby suggesting that the tongue height of the Japanese speakers was lower than that of the English speaker. The same tendency, though somewhat weak, was observed in the second word position. On the other hand, the F2 values relating to the front-back feature did not very clearly distinguish between the English speaker and the Japanese speakers. However, the male English speaker was more different both in F1 and in F2 in each word position from the male Japanese speakers.

For /u/, the F1 values in the first word position were significantly lower for the English speaker than for one or both of the Japanese speakers, the results of which may be attributable to the Japanese speakers' characteristic feature [- rounding]. The F1 values in the second word position were relatively higher even for the English speaker and did not exhibit a simple pattern. This is probably because the vowel in this position was unstressed and reduced to a somewhat schwa-like vowel. Evidence in support of this interpretation was the lower mean F0 value in the second word position than that in the first for the English speaker. The patterns of the F2 values were more complicated than those of the F1 values, but evidently related to accent patterns. We will discuss some of them later.

For /ɑ/, the F1 and F2 values varied according to individuals and items. The English speaker's F1 value for *c<u>ar</u> user* was significantly higher than Japanese speaker 2's but did not differ from Japanese speaker 1's. The English speaker's F1 value for

F<u>ar</u> East was *lower* than Japanese speaker 1's but approximately the same as Japanese speaker 2's. It may be noted that the F 1 value of the English speaker was significantly lower for *F<u>ar</u> East* than for *c<u>ar</u> user*. Again, this may be due to the result that the English speaker less accented *F<u>ar</u>* as compared to *c<u>ar</u>*. Such a tendency was not observed for the Japanese speakers. The F2 values did not seem to show the results which are consistent with the smaller point-vowel space hypothesis.

In summary, the results shown in Tables 1 and 2 were that while some accented point vowels produced by the English speakers were more peripherally placed in the F1/F2 space than the Japanese speakers, unaccented point vowels distinguished to a lesser degree between the English speakers and the Japanese speakers.

To ascertain that the area of the triangle formed by the accented point vowels is indeed larger for the English speakers than for the Japanese speakers, we selected the /i/ in *p<u>ea</u>ce march*, the /u/ in *tr<u>ue</u> peace*, and the /ɑ/ in *c<u>ar</u> user* to compare the areas of the vowel triangles between the speakers. Table 3 summarizes the results and Figure 1 visualizes the female results.

TABLE 3 AND FIGURE 1 GO ABOUT HERE

Here, too, let us look only at the female results. As can be seen in Table 3, the effect of speaker was significant, $F(1, 9) = 76.45$, $p < .001$, and the English speaker's space size (153,469 Hz^2) and Japanese speaker 1's (174,093 Hz^2), which were not significantly different between each other, $p > .2$, were both significantly greater than Japanese speaker 2's (36,156 Hz^2), $p < .001$. We thus conclude that the present results are basically consistent with the smaller point-vowel space hypothesis although one of the female Japanese speakers seems to have acquired to expand the point-vowel space.

Schwa vowels

Tables 4 and 5 show the mean F1 and F2 values of each schwa (i.e., second vowel) of the five experimental words for the female and male speakers, respectively.

TABLES 4 AND 5 GO ABOUT HERE

Here, too, we describe only the major results from the female speakers in some detail. As can be seen from Table 4, the F1 and F2 values greatly vary across the words, and the word *spoonful* seems to be an exception for all three speakers. Thus, with *spoonful* excluded, the difference between the highest and lowest F1 values for the English speaker was found to be only 28 Hz and the difference between the highest and lowest F2 values, 276 Hz although the effects of word on those values were still significant. In contrast, the differences between the highest and lowest F1 and F2 values were 473 Hz and 857 Hz for Japanese speaker 1 and 334 Hz and 1321 Hz for Japanese speaker 2, respectively. These findings are consistent with the greater schwa-space hypothesis for Japanese speakers. Figure 2 also indicates the validity of this hypothesis regarding the schwa voweos in *chicken*, *Tarzan*, and *spoonful*. To statistically verify the hypothesis, we compared the triangle areas between the speakers. The effect of speaker was highly significant, $F(2, 9) = 296.36$, $p < .001$. The mean area 12,280 Hz^2 for the female English speaker was far smaller than those 103,654 Hz^2 and 148,123 Hz^2 for female Japanese speakers 1 and 2, these latter speakers' areas were not significantly different between them. Basically the same results were observed for the male speakers. We thus conclude that the present findings are consistent with the greater schwa-space hypothesis, namely that the Japanese speakers' schwa vowels span greater vowel space in the F1-F2 vowel space than do the native English speakers'.

FIGURE 2 GOES ABOUT HERE

As was expected, the effects of word on F1 and F2 values for schwas, however, varied greatly across individual words and speakers, and we tested the longer vowel-distance hypothesis taking the variability in account. The results are presented in Tables 6 and 7 for the female and male speakers.

TABLES 6 AND 7 GO ABOUT HERE

From Tables 6 and 7 we see that *common* is the only word that is consistent with the shorter vowel-distance hypothesis, the vowel distance clearly distinguishing between the English speakers and the Japanese speakers.

Related to this, inspection of the first and second vowels *common* suggested that the Japanese speakers' second vowel was not schwa-like but somewhat similar to the first vowel. More specifically, the same vowel-schwa hypothesis was tested by comparing the F1 and F2 values of the first vowel and those of the schwa in each word. The results are shown in Table 8.

TABLE 8 GOES ABOUT HERE

As can be seen from Table 8, the first part of the longer vowel-distance hypothesis (i.e., the first and second vowels in word such as *chicken* and *Tarzan* are the same or similar for Japanese speakers) is not fully supported; instead, only a general tendency for the Japanese speakers' first vowel and second schwa to be more similar than the English speakers' is suggested. For example, for female Japanese FJ2, the F1 values were not significantly different between the first vowel and schwa for *redden* and *spoonful*; and the F2 values were not significantly different between these vowels for *common*. By contrast, for the female English speaker, the F1 and F2 values were greatly different between these vowels except for the F1 value of *spoonful*.

Discussion

A precise description of English vowel quality of Japanese speakers of English has been unavailable. This study examined the smaller point-vowel space hypothesis for the three point vowels /i, u, ɑ/ and the greater schwa-space and longer vowel-distance hypotheses for the schwa vowel.

The smaller point-vowel space hypothesis

The smaller point-vowel space hypothesis that Japanese speakers' point-vowel space formed in the F1-F2 vowel space is smaller than English speakers' when the point vowels /i, u, ɑ/ are accented in clear speech was basically supported, and one of the female Japanese speakers produced as large a vowel space as the female English speaker (see Figure 1). Probably, this female Japanese speaker had acquired the vowel space of these English point vowels. If so, it would indicate that L1 interference, though real and prevalent extensively, is relatively easier to overcome.

The reduction of vowel space in Japanese speakers, however, does not mean that the vowel space uniformly shrinks across the board. Rather, the tongue height and front-back features vary depending on individual point vowels and also on linguistic contexts. Specifically, for the accented /i/, the Japanese speakers showed a lower degree of tongue height (see Table 1 and Figure1), but were generally the same as the English speakers in terms of the front-back dimension. Likewise, for the accented /u/, the Japanese speakers' F1 values tended to be lower as compared to the English speakers' (Table 1 and Figure 1). We don't know whether this indicates that the Japanese speakers' tongue height was lower than the English speakers' or whether that is attributable to the possibility that the Japanese speakers have the [-rounding] feature for /u/ or both.

The greater schwa-space and longer vowel-distance hypotheses

In marked contrast to the smaller point-vowel space hypothesis was the greater schwa-space hypothesis, the finding which suggests that the effect of L1 was so potent that none of the Japanese speakers were able to reduce the schwas (Figure 2). While the general picture which emerged here was expanded schwa space for the Japanese speakers, the patterns of the relations of their schwas to the English speakers' greatly varied depending on the word contexts, and we will take a brief look at each case for the female group below.

For *common*, the Japanese speakers' schwas were more outwardly located with the place much lower and more backed than the English speakers', so that they resemble Japanese /a/ rather than its /o/ (cf. Vance, 2008, p. 70). This case may be viewed as a paradigm example of L1 interference if we assume that the difference between Japanese /a/ and /o/ is not very large.

For *chicken*, the Japanese speakers' F2 values were greater than the English speaker's, thus suggesting that their schwas are more peripherally placed in the front-back dimension, i.e., more /i/-like in this respect although Japanese speaker 2's F1 value is much higher than the typical F1 value of /i/. However, note also that Japanese speaker 1 produced higher F1 and higher F2 values for the schwa in *chicken* (579 Hz and 2,348 Hz) than the point vowel in *peace* (268 Hz and 2,903 Hz), thus indicating that she had acquired the basic features of English schwa.

Tarzan is of interest in that the two Japanese speakers differentially learned the target F1 and F2 values; that is, Japanese speaker 1 had a F2 value of 1,922 Hz, which was close to the English speaker's 1,937 Hz, whereas her F1 value 677 Hz was significantly different from the English speaker's 490 Hz (Table 4). Japanese speaker 2 exhibited an opposite pattern, whose F1 value 482 Hz was not significantly different from the English speaker's but her F2 value 1,840 Hz was significantly lower than the English speaker's.

Redden is also of interest in that it shows a difference between the Japanese speakers. In the Method section, we hypothesized that if the effect of the learning of the <-den> and /-dun/ or /-don/ association is great enough, the distance between the vowels in *redden* would be longer than those for the other words. However, Japanese speaker 2 exhibited a reverse pattern, i.e., the distance between the vowels being the shortest for this word than for the other words, which indicates that this speaker pronounced *red* and *den* in *redden* in a more similar manner than the two vowels in the other words (see Tables 6 and 8).

For *spoonful*, Japanese speaker 1 had a similar F2 value to, but a different F1 value from, the English speaker's, whereas Japanese speaker 2 had a similar F1 value to, but a different F2 value from, the English speaker's. Just like the case of *Tarzan*, the Japanese speakers might differentially have acquired the features of the schwa in this condition.

Finally, the findings shown in Table 8 are interpreted as partial support for the first part of the longer vowel-distance hypothesis. While the English speakers showed great differences in F1 and F2 between the first and second vowels in all words except *spoonful*, some similarities between the vowels were observed for the Japanese speakers except for *Tarzan*. Regarding *Tarzan*, however, inspection of the F1 and F2 values indicates that the Japanese speakers' schwas were less reduced or centralized as compared the English speakers'

Further research

The present study has taken only a first step in broader research on Japanese learners' vowel quality in English. As such, many questions remain for future investigations, and we mention some of them here.

A first question to ask may be whether and how vowel quality as found in this study contributes to the putatively low intelligibility noted for spoken English words produced by Japanese speakers. Perceptual research is needed to provide an answer to this question, in which the quality of vowels in words such as *pin*/*pen*, *cut*/*cot*, and *set*/*sat* produced by Japanese speakers may be examined using identification and discrimination tasks.

A second question of interest may be what English vowels are difficult for Japanese (and other language) speakers to acquire and why. The schwas in some context may be more difficult than those in other context. The relationship between Japanese and English vowel reduction in Japanese speakers remains largely unknown. While Kondo (2000, p. 30) says that "there is no phonological reduction in Japanese," Vance (2009, p. 69) states that "Japanese vowels in connected speech tend to become centralized, which makes them less distinct from each other." Vowel reduction itself would be a natural phenomenon whatever language one may speak, but the learnability of the vowel reduction in a particular context in a target language is a separate issue to be addressed in future research. This study suggests, for example, that, of the five word conditions, the schwa in *common* is most different between the English speakers and the Japanese speakers (see Tables 4 and 5) and thus probably most difficult for Japanese learners to acquire.

A third question which we find interesting involves the possible variability in vowel quality within speakers. In the case of English speakers who read a passage out loud, vowels tend to be reduced when the words including them appear the second time in the text (Tomita, 2006). We compared the F1 and F2 values of vowels produced on the first and second trials. The patterns were rather complicated, some vowels being reduced and centralized and other remaining invariant. This issue seems important because Smiljanic and Bradlow (2005) concerning clear speech in Japanese assert that "it is likely that Japanese talkers would not expand their vowel space in clear speech" (p. 1684). However, Jean Andruski (personal communication), who carried out a study of Japanese infant-directed speech, states that Japanese mothers' increases in vowel space size were not as great as they saw in American English, Swedish, and Russian mothers' speech. This may be interpreted as suggesting that there is less vowel space expansion and reduction in Japanese. This possibility thus involves the learnability of the English point vowels.

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Table 1

Mean F1 and F2 Values of Three Point Vowels for the Female Speakers

/i/		FE	FJ1	FJ2	Mean	*F*-value[a]	*p*-value	Comparison
*tea**	F1	276	296	335	302	49.44	< .001	FE < FJ1 < FJ2
	F2	2783	2845	2866	2831	0.64	*n.s.*	FE, FJ1, FJ2
*peace**	F1	268	331	322	307	44.18	< .001	FE < FJ2, FJ1
	F2	2903	2956	2646	2835	29.17	< .001	FJ2 < FE, FJ1
Mean	F1	272	313	328	305			
F-value		3.12[b]	13.39[b]	10.32[b]				
p-value		> .05	< .01	< .01				
Mean	F2	2843	2901	2756				
F-value[b]		1.42	5.50	41.83				
p-value		*n.s.*	< .05	< .001				
*peace***	F1	316	350	313	326	6.99	< .01	FJ2, FE < FJ1
	F2	2920	2861	2899	2893	2.73	> .05	FJ1, FJ2, FE
*East***	F1	295	362	359	339	63.95	< .001	FE < FJ2, FJ1
	F2	2949	3032	2747	2909	117.5	< .001	FJ2 < FE < FJ1
Mean	F1	272	313	328	305			
F-value[b]		3.86	3.28	17.70				
p-value		> .05	> .10	< .01				
Mean	F2	2935	2947	2823				
F-value[b]		1.88	50.25	37.23				
p-value		*n.s.*	< .001	< .001				

[a] The degrees of freedom are all 2 and 29. [b] The degrees of freedom are all 1 and 9.

* First position, ** Second position.

Table 1 (cont.)

/u/		FE	FJ1	FJ2	Mean	*F*-value[a]	*p*-value	Comparison
*true**	F1	352	392	393	379	10.43	< .001	FE < FJ1, FJ2
	F2	2000	1806	1755	1854	12.22	< .001	FJ2, FJ1 < FE
*two**	F1	331	385	362	359	36.49	< .001	FE < FJ2 < FJ1
	F2	1839	1988	1606	1811	29.81	< .001	FJ2 < FJ1
Mean	F1	342	389	378	370			
F-value		25.22	0.25	15.15				
p-value		< .001	> .05	*n.s.*				
Mean	F2	1920	1897	1681				
F-value[b]		11.19	21.79	7.35				
p-value		< .01	< .001	< .05				
*spoon***	F1	430	396	318	381	35.08	< .001	FJ2 < FJ1 < FE
	F2	2210	1464	1188	1621	98.66	< .001	FJ2 < FJ1 < FE
*pool***	F1	381	361	391	378	4.40	< .05	FJ1 < FJ2***
	F2	836	915	978	910	18.37	< .001	FE < FJ1 < FJ2
Mean	F1	405	379	354	379			
F-value		17.18[b]	12.62[b]	31.36[b]				
p-value		< .01	< .001	< .01				
Mean	F2	1523	1190	1083				
F-value[b]		2012	506.7	6.21				
p-value		< .001	< .001	< .05				

[a] The degrees of freedom are all 2 and 29. [b] The degrees of freedom are all 1 and 9.

* First position, ** Second position. *** FJ1, FE & FE, FJ2, where neither the difference between FJ1 and FE nor that between FE and FJ2 was significant.

Table 1 (cont.)

/ɑ/		FE	FJ1	FJ2	Mean	F-value[a]	p-value	Comparison
*c<u>ar</u>**	F1	754	731	524	670	47.86	< .001	FJ2 < FJ1, FE
	F2	1374	1127	1018	1173	48.26	< .001	FJ2 < FJ1 < FE
*F<u>ar</u>**	F1	681	781	522	661	154.6	< .001	FJ2 < FE < FJ1
	F2	1139	1154	1501	1265	35.54	< .001	FE, FJ1 < FJ2
Mean	F1	718	756	523	666			
F-value		7.34	4.89	0.04				
p-value		< .05	< .06	*n.s.*				
Mean	F2	1256	1141	1259				
F-value[b]		31.91	1.71	78.34				
p-value		< .001	*n.s.*	< .001				
*<u>Ar</u>ms***	F1	482	808	458	583	75.43	< .001	FJ2, FE < FJ1
	F2	993	1084	1063	1047	7.29	< .01	FE < FJ2, FJ1
*M<u>ar</u>ch***	F1	451	827	423	567	262.2	< .001	FJ2, FE < FJ1
	F2	1200	1111	1239	1183	2.81	> .05	FJ1, FE, FJ2
Mean	F1	467	817	440	575			
F-value		5.30	0.53	1.02				
p-value		< .05	*n.s.*	*n.s.*				
Mean	F2	1920	1897	1681	1833			
F-value[b]		11.19	21.79	7.35				
p-value		< .01	< .001	< .05				

[a] The degrees of freedom are all 2 and 29. [b] The degrees of freedom are all 1 and 9.

* First position, ** Second position.

Table 2

Mean F1 and F2 Values of Three Point Vowels for the Male Speakers

/i/		ME	MJ1	MJ2	Mean	*F*-value[a]	*p*-value	Comparison
*tea**	F1	251	278	273	267	35.01	< .001	ME < MJ2, MJ1
	F2	2317	2206	2073	2199	28.87	< .001	MJ2 < MJ1 < MJ1
*peace**	F1	264	276	265	269	5.03	< .05	ME, MJ2 < MJ1
	F2	2414	2252	2152	2273	28.58	< .001	MJ2 < MJ1 < ME
Mean	F1	258	277	269				
F-value[b]		9.02	0.26	7.10				
p-value		< .05	n.s.	< .05				
Mean	F2	2366	2229	2113				
F-value[b]		5.64	2.79	12.30				
p-value		< .05	> .10	< .001				
*peace***	F1	251	270	227	249	21.21	< .001	MJ2 < ME < MJ1
	F2	2339	2238	2154	2244	12.27	< .001	MJ2 < MJ1 < ME
*East***	F1	223	267	256	249	68.17	< .001	ME < MJ2 < MJ1
	F2	2355	2265	2183	2268	20.83	< .001	MJ2 < MJ1 < ME
Mean	F1	237	269	241				
F-value[b]		58.67	0.39	14.75				
p-value		< .001	*n.s.*	< .01				
Mean	F2	2347	2252	2169				
F-value[b]		0.60	0.71	0.99				
p-value		*n.s.*	*n.s.*	*n.s.*				

[a] The degrees of freedom are all 2 and 27. [b] The degrees of freedom are all 1 and 9.

* First position, ** Second position.

Table 2 (cont.)

/u/		ME	MJ1	MJ2	Mean	F-value[a]	p-value	Comparison
true*	F1	307	309	293	303	8.42	< .001	MJ2 < ME, MJ1
	F2	1293	1178	1678	1381	65.60	< .001	MJ1 < ME < MJ2
two*	F1	289	279	292	287	3.56	< .05	MJ1, ME < ME, MJ2
	F2	1348	1312	1852	1504	42.19	< .001	MJ1, ME < MJ2
Mean	F1	298	294	293				
F-value		12.79	60.18	0.07				
p-value		< .01	< .001	*n.s.*				
Mean	F2	1320	1245	1762				
F-value[b]		1.28	3.25	22.83				
p-value		*n.s.*	> .10	< .001				
spoon**	F1	325	310	245	293	7.25	< .001	MJ2 < MJ1 < ME
	F2	1419	1023	1120	1187	43.98	< .001	MJ1, MJ2 < ME
pool**	F1	323	296	317	312	5.85	< .01	MJ1 < MJ2, ME
	F2	675	972	1353	1000	184.2	< .001	MJ1 < MJ2, ME
Mean	F1	324	303	281				
F-value[b]		0.14	1.56	8.88				
p-value		*n.s.*	*n.s.*	< .02				
Mean	F2	1047	997	1236				
F-value[b]		850.5	4.76	12.03				
p-value		< .001	< .06	< .01				

[a] The degrees of freedom are all 2 and 27. [b] The degrees of freedom are all 1 and 9.

* First position, ** Second position.

Table 2 (cont.)

/ɑ/		ME	MJ1	MJ2	Mean	*F*-value[a]	*p*-value	Comparison
car*	F1	541	514	646	567	47.86	< .001	MJ1, ME < MJ2
	F2	1074	1026	1240	1113	25.01	< .001	MJ1, ME < MJ2
Far*	F1	565	520	643	576	32.82	< .001	MJ1 < ME < MJ2
	F2	951	921	1162	1011	116.0	< .001	MJ1, ME < MJ2
Mean	F1	553	517	644				
F-value		1.34	0.38	0.00				
p-value		*n.s.*	*n.s.*	*n.s.*				
Mean	F2	1012	973	1200				
F-value[b]		36.49	33.33	5.80				
p-value		< .001	< .001	< .05				
Arms**	F1	462	699	624	595	59.91	< .001	ME < MJ2 < MJ1
	F2	968	1062	1852	1294	448.2	< .001	ME < MJ1 < MJ2
March**	F1	520	781	592	631	75.79	< .001	ME < MJ2 < MJ1
	F2	1215	1071	1216	1167	12.68	< .001	MJ1 < ME, MJ2
Mean	F1	491	740	608				
F-value		26.11	8.95	2.53				
p-value		< .001	< .05	*n.s.*				
Mean	F2	1091	1066	1236				
F-value[b]		104.6	0.11	1.91				
p-value		< .001	*n.s.*	*n.s.*				

[a] The degrees of freedom are all 2 and 27. [b] The degrees of freedom are all 1 and 9.

* First position, ** Second position.

Table 3

Mean Vowel Spaces (Hz^2) for Individual Speakers

Female	Mean	Male	Mean
FE	153,469	ME	126,314
FJ1	174,093	MJ1	107,752
FJ2	36,156	MJ2	77,755
F-value	76.45		7.83
df	1, 9		1, 9
p-value	< .001		< .01
Comparison	FJ1, FE > FJ2	MJ2, MJ1; MJ1, ME; MJ2 < ME	

Table 4

Mean F1 and F2 Values of the Schwa of Each Test Word for the Female Speakers

	FE	FJ1	FJ2	*F*-value[a]	*p*-value	Comparison
common						
F1	511	834	652	197.2	< .001	FE < FJ2 < FJ1
F2	1939	1491	1467	75.50	< .001	FJ2, FJ1 < FE
chicken						
F1	518	579	318	36.49	< .001	FJ2 < FE, FJ1
F2	2213	2348	2788	93.57	< .001	FE, FJ1 < FJ2
Tarzan						
F1	490	677	482	31.28	< .001	FJ2, FE < FJ1
F2	1937	1922	1840	3.34	< .06	FJ2, FJ1, FE
redden						
F1	501	361	504	24.52	< .001	FJ1 < FE, FJ2
F2	2151	2070	2062	12.57	< .001	FJ1, FJ2 < EF
spoonful						
F1	378	477	372	55.53	< .001	FJ2, FE < FJ1
F2	863	827	662	94.53	< .001	FJ2 < FJ1 < FE
F1 *M*[b]	480	586	466			
F1 *F*[c]	97.88	72.67	87.04			
p	< .001	< .001	< .001			
F2 *M*[b]	1821	1732	1764			
F2 *F*[c]	1570	477.0	836.8			
p	< .001	< .001	< .001			

[a] The effect of speaker (df = 2, 27).

[b] The mean with *spoonful* excluded.

c The effect of word (df = 1, 9) with *spoonful* excluded.

Table 5

Mean F0, F1, and F2 Values of the Schwa of Each Test Word for the Male Speakers

	ME	MJ1	MJ2	*F*-value[a]	*p*-value	Comparison
common						
F1	356	713	683	177.9	< .001	ME < MJ2 < MJ1
F2	1508	1761	2054	xx.50	< .001	
chicken						
F1	351	437	187	65.31	< .001	MJ2 < ME, MJ1
F2	1821	2348	2269		< .001	
Tarzan						
F1	423	323	312	4.50	< .05	MJ2, MJ1; MJ1, ME
F2	1763	1260	1522		< .06	
redden						
F1	373	330	281	16.52	< .001	MJ1 < MJ2 < ME
F2	1761	1762	1751		< .001	
spoonful						
F1	414	308	259	71.51	< .001	MJ2 < MJ1 < MJ1
F2	737	850	1349		< .001	
F1 *M*[b]	383	422	344			
F1 *F*[c]						
p						
F2 *M*[b]						
F2 *F*[c]						
p	< .001	< .001	< .001			

[a] The effect of speaker (df = 2, 27).

[b] The mean with *spoonful* excluded.

c The effect of word (df = 1, 9) with *spoonful* excluded.

Table 6

Mean Distance (Hz) between the Constituent Vowels of Each Test Word

for the Female Speakers

	FE	FJ1	FJ2	Mean	*F*-value[a]	*p*-value	Comparison
1. *common*							
/ɑ-ə/	752	285	290	442	90.31	< .001	FJ1, FJ2 < FE
2. *chicken*							
/ɪ-ə/	220	212	177	203	0.35	*n.s.*	FJ2, FJ1, FE
3. *Tarzan*							
/ɑ-ə/	595	706	589	630	1.19	*n.s.*	FJ2, FE, FJ1
4. *redden*							
/ɛ-ə/	235	394	107	245	51.31	< .001	FJ2 < FE < FJ1
5. *spoonful*							
/u-ə/	569	535	321	475	3.49	< .05	FJ2, FJ1, FE
Mean	474	426	297	399			
F-value[b]	20.35	38.44	13.80				
p-value	< .001	< .001	< .001				

Between-speaker comparison: FJ2 < FJ1, FE

Within FE: 2, 4; 4 < 5, 3; 5, 1; 3 < 1

Within FJ1: 2, 1 < 4 < 5 < 3

Within FJ2: 4, 2; 2, 1; 1, 5; 2 < 5 < 3; 1 < 3

[a] The degrees of freedom are all 2 and 29.

[b] The degrees of freedom are all 4 and 36.

Table 7

Mean Distance (Hz) between the Constituent Vowels of Each Test Word

for the Male Speakers

	ME	MJ1	MJ2	Mean	*F*-value[a]	*p*-value	Comparison
1. *common*							
/ɑ-ə/	452	772	1048				
2. *chicken*							
/ɪ-ə/	240	374	242				
3. *Tarzan*							
/ɑ-ə/	618	440	317				
4. *redden*							
/ɛ-ə/	156	328	196				
5. *spoonful*							
/u-ə/	528	196	222				

Table 8

Differences in F1 and F2 Values between the First Vowel and Second Schwa in Each Test Word for Each Speaker

	Female speakers			Male speakers		
	FE	FJ1	FJ2	ME	MJ1	MJ2
common						
F1	7.36***	0.06	13.3***	8.08***	7.18***	4.24**
F2	34.7***	5.40***	1.16	14.0***	12.5***	3.12**
chicken						
F1	25.1***	4.01**	5.16***	0.49	6.95***	6.30***
F2	8.28***	1.61	2.66*	4.91***	5.58***	0.74
Tarzan						
F1	5.57***	3.78**	2.67*	4.24**	8.61***	4.57***
F2	9.81***	20.1***	6.78***	13.6***	6.99***	1.54
redden						
F1	12.3***	24.9***	0.72	12.3***	0.81	12.1***
F2	30.2***	2.93*	3.55**	0.43	5.77***	4.35**
spoonful						
F1	1.93	0.22	0.11			
F2	5.41***	22.8***	5.12***			

t-value *$p < .05$, **$p < .01$, ***$p < .001$.

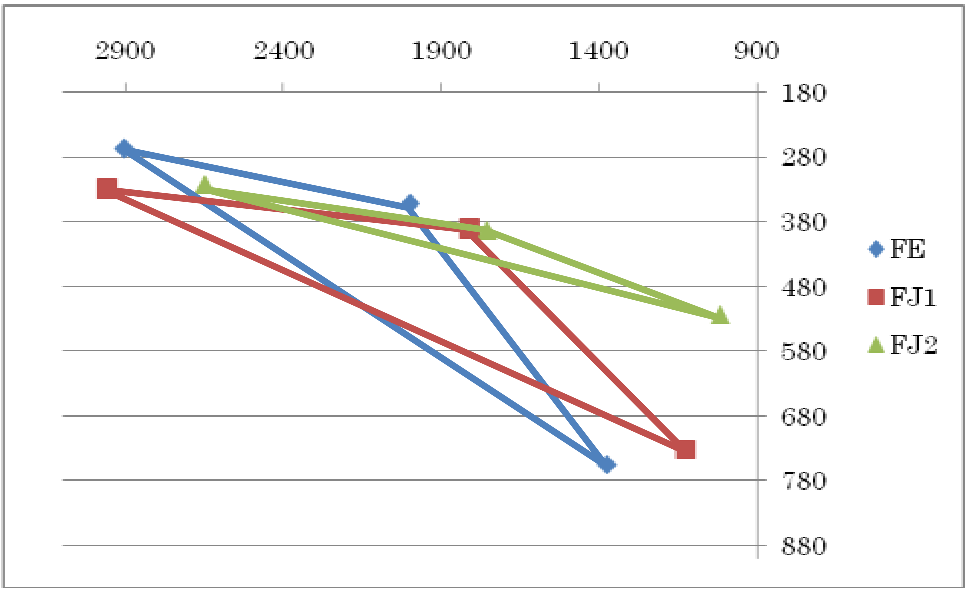

Figure 1. English point-vowel spaces for the female English speaker and the two female Japanese speakers.

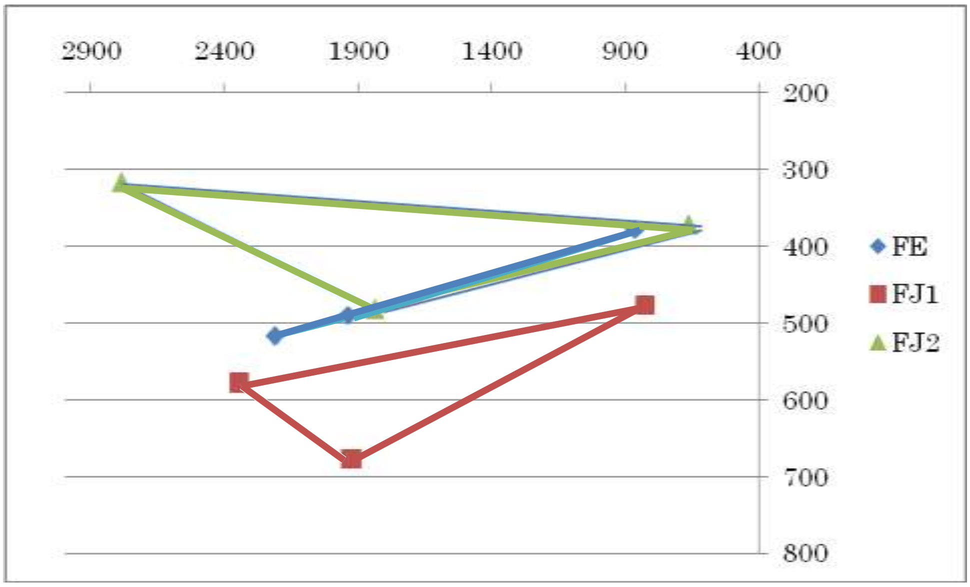

Figure 2. English schwa spaces for the female English speaker and the two female Japanese speakers.