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Quality Variation of the English Schwa*

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0. Introduction

English has a vowel called "schwa" as many other languages do. It is well-known that this vowel appears only in unaccented syllables with the highest frequency of occurence (cf. Cruttenden 1994). Its articulatory characteristics have been examined in previous studies. Two analyses are made: Jones (1960) divides /ə/ into three variants ; Wells (1990) shows only the range in which /ə/ occurs on the vowel chart (cf. Figure 4). However, these analyses seem to be insufficient, since some schwas behave differently from the prediction by theses analyses, as we will see in Section 2. Thus it is also necessary to analyze the acoustic aspects of /ə/.

While /ə/ is inspected in detail from the articulatory viewpoint, there are few previous studies on acoustic properties of /ə/ (cf. Fowler 1981). Since /ə/ is always weak (i.e., unstressed) and experimental instruments was not elaborated enough until recently, it was impossible to extract the acoustic characteristic peculiar to /ə/ occurring in actual utterance. However, the improvement of instruments for acoustic analysis allows us to investigate /ə/ precisely.[1]

The aim of this paper is to answer the two following questions:

a. Is it possible to divide /ə/ as three variants as in previous studies with its tongue-height and tongue-position?
b. What is the properties to determine each of the /ə/ variants?

For this purpose, we will first review some previous studies. We will then analyze the examples of the English schwa, utilizing the last experimental instruments, to reveal the spectral properties and the frequency range on the vowel chart where /ə/ actually appears. On the basis of the results of the acoustic analysis, we will point out that the description of /ə/ in previous studies is unsatisfactory. Further, we will consider what serves as a factor for the determination of /ə/.

1. Previous studies from the articulatory viewpoint

1.1. Jones (1960)

Jones classifies the English schwa in three variants denoted by ə₁, ə₂ and ə₃ according to articulation and quality. The tongue-height and the tongue-position (i.e., backness) of the three vowels are represented in Figure 1 (cited from Jones (1960)).

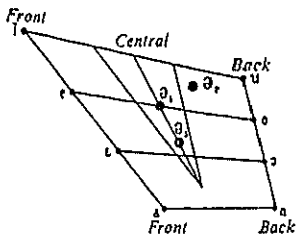

Figure 1. Jones' (1960) vowel chart

To put roughly first, ə₁ and ə₃ belong to a central vowel, and they are represented on the central line in Figure 1. ə₂ is a kind of back vowel, more precisely an advanced version of close back unrounded vowel [ɯ].[2] In what follows, we review each of them taking concrete examples.

1.1.1. The variant ə₁

Jones regarded ə₁ as "the principal member" of the English schwa. This variant is articulated as a vowel having a tongue-height of half-close. This type of schwa is exemplified by the underlined vowels in the following words and phrases:

a. a̲long, a̲ttempt, a̲dmit, o̲bserve
b. gentlema̲n, manne̲rs, lemo̲n, choru̲s
c. the̲ table, a̲ window

This variety of schwa is the most typical one because this vowel is least restricted on the environment where it occurs. The examples above show that ə₁ can occur in any position other than the word-final one: the examples in (a) occur word-initially; those in (b) word-medially; those in (c) in phrases.

1.1.2. The variant ə₂

The variant ə₂ is "higher and more retracted" than ə₁, and it is observed in the position next to the velars [k], [g] and [ŋ] as follows:

co̲ndemn, to̲ go, back a̲gain, the̲ ground, hypo̲crit, suffo̲cate.

ə₂ is described as a kind of [ɯ], i.e., as a more retracted version than ə₁. However, the description of this variant seems to be problematic. Rather, we suppose that ə₂ be an advanced variety of /ə/. An acoustic study on velar consonants in Olive, Greenwood and Coleman (1993) reveals that velars affect their preceding or following vowels and that the F2 of the vowels is raised toward velar consonants. F2 is an acoustic component of a vowel, which corresponds to its tongue-position (i.e., backness). If F2 is raised, then a vowel is articulated with the advanced tongue-position (cf. Ladefoged 1993). Therefore, the effect of velar consonants to their neighboring vowels predicts that schwas in the vicinity of velar consonants are not retracted but advanced, having the quality of [ɪ]. We will see whether this is true or not in section 2.

1.1.3. The variant ə₃

ə₃ is observed in word-final positions as illustrated in the following examples:

China, villa, collar, over, manner, bitter, farther,
actor, honour, picture, borough, thorough

In Jones' description, the variant ə₃ is more open than ə₁ and ə₂ and it is never replaced for the other members. In other words, if a schwa appears in word-final positions, it is always ə₃. We will examine whether this description of ə₃ is adequate or not in the following section.

To sum up, Jones recognizes three sounds as the variants of the English schwa, noting the difference in the tongue-position and the tongue-height in articulation. He first describes the typical member ə₁ and classifies each of the rest as a variant depending on the particular environment in which it occurs.

1.2. Gimson (1989), Takebayashi (1982) and Wells (1990)

Gimson (1989) and Takebayashi (1982) classify the English schwa in almost the same way as does Jones. There are two noticeable revision of the tongue-position displayed in Figures 2 and 3.

Gimson describes the typical member, namely ə₁ in Jones' (1960)

description, as the vowel having the tongue-height between half-close and half-open. The tongue-height of the variant ə₃ is also lowered from a half-open vowel to a vowel with a tongue-height between half-open and open. As regards ə₂, the degree of its tongue-retraction and raising is smaller than that in Jones' description but the slight retraction and raising is still retained.

Interestingly, Takebayashi (1982) revises the tongue-position of schwas next to velars. He regards these schwas, namely Jones' ə₂, as a raised variant of the schwa phoneme with no retraction of the tongue.

While Gimson and Takebayashi recognize /ə/ as having three variants as does Jones, Wells (1990) only illustrates the region in which /ə/ occurs on the vowel chart as shown in Figure 4.

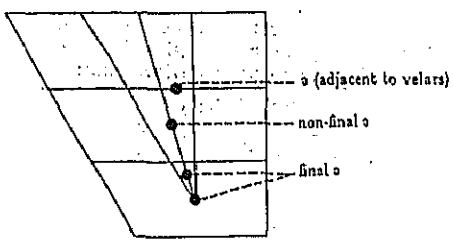

Figure 2. Gimson's (1989) vowel chart

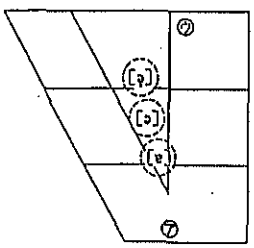

Figure 3. Takebayashi's (1982)vowel chart

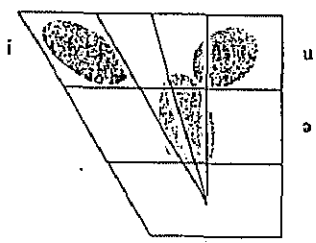

Figure 4. Wells' (1990) vowel charts

It is worth considering what makes him not classify /ə/ into several variants. We will investigate this issue further on the basis of the results of the experiment in section 2.

2. Experiment

The previous studies reviewed above show that the English schwa has three allophones, each of which has its own tongue-height and tongue-position. In contrast, Wells (1990) describes the English schwa as spreading out over a central region of the vowel chart and no specific variant, which correspond to Jones' ə₁, ə₂ and ə₃. The aim of this experiment is to examine the spectral features of the English schwa and to determine its tongue-height, tongue-position and quality. The result of this experiment will lead us to describe correctly the variants of the English Schwa.

2.1. Methodology

All the phonetic data for the experiment were obtained from Shimaoka and Wells (1992) and Fletcher (1990). The phonetic data were pronounced by RP speakers and recorded in a audio cassette tape. As an instrument for the analysis in this experiment, CSL 4300 (KAY Elemetrics corporation) was utilized. I first analyzed each of the schwas to measure the maximum of amplitude. Then, at the position with the largest degree of amplitude, the values of F1, F2 and F3 were measured.

2.2. Result

The numerical results in the present study are all illustrated in Table 1.

		F1(Hz)	F2(Hz)	F3(Hz)
(1)	[ə]³	543	1276	2565
(2)	[ə]⁴	721	1337	2654
(3)	"about"	599	1270	2559
(4)	"support"	361	1209	2586
(5)	"American"	560	1240	2480
(6)	"hidden"	471	1521	2563
(7)	"Britain"	354	1400	2394
(8)	"lemon"	435	1267	2762
(9)	"happen"	548	1362	2604
(10)	"sudden"	510	1422	2778

(11)	"possible"	461	1153	2513
(12)	"softener"	545	1310	2530
(13)	"opposite"	326	1377	2560
(14)	"common"	592	1151	2680
(15)	"atmospheric"	273	1286	2748
(16)	"fastened"	417	1248	2511
(17)	"payment"	615	1332	2743
(18)	"famous"	474	1356	2795
(19)	"awaken"	573	1176	2332
(20)	"serious"	529	1770	2924
(21)	"American"	560	1580	2220
(22)	"secondary"	410	1669	2298
(23)	"awaken"	517	1459	2418
(24)	"leader"	505	1367	2637
(25)	"sister	618	1378	2579
(26)	"leather"	616	1339	2525
(27)	"leisure	656	1587	2522
(28)	"pleasure"	586	1534	2515
(29)	"catcher"	582	1572	2598
(30)	"ladder"	629	1453	2704
(31)	"other"	621	1368	2519
(32)	"author"	716	1360	2594
(33)	"conquer"	429	1517	2421
(34)	"softener"	480	1320	2830
(35)	"comma"	596	1241	2701

Table 1. Numerical values of the schwas

Table 1 shows the values of F1 through F3, which schwas used in this experiment contain. It is generally said that F1, F2 (and F3) play an important role in distinguishing one vowel from another, namely in determining the quality of vowels.

To examine closely the quality of the schwas in Table 1, we first consider the values of F1 and F2. Using their values, we make the following chart.

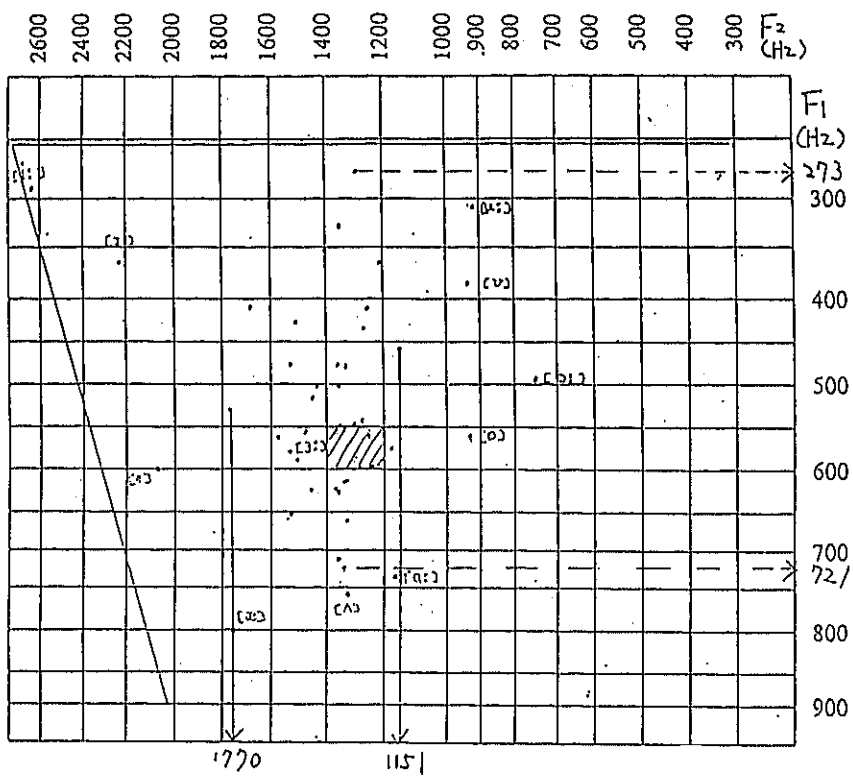

Figure 5. The region of all the schwas in the present study

In Figure 5, the vertical axis shows the value of F1, and the horizontal axis the value of F2. The change of a value on the vertical axis corresponds to the degree of tongue-height (or the aperture of the lower jaw). A vowel with a smaller value of F1 lies in a upper position on the chart than that with a larger value; in this case, the tongue-height of the former vowel is in a smaller degree than that of the latter vowel. On the other hand, the change of a value on the horizontal axis is closely related to the back-and-forth movement of the tongue. When a value of F2 is larger, i.e., a vowel is in a lefter position in the chart, the tongue is put more forward in the mouth. Square-bracketed vowels, which function as Jones' cardinal vowels in Figure 1, are plotted on this chart in order to show the relation between the schwas and them clearly.[8]

2.3. Observation and analysis

2.3.1. The central region of the schwa

First of all, consider Figure 4, in which all the schwas in the present study are plotted, in order to restrict the range of /ə/. The vowels occur in the range from 273 Hz to 721 Hz along the vertical line and along the horizontal line from 1151 Hz to 1770 Hz.

Next we search the central part of the range by considering the data in Table (2a-b).

Frequency(Hz)	Number	Percentage(%)
1100-1200	3	8.6
1200-1400	21	60.0
1400-1600	9	25.7
1600-1800	2	5.7

Table 2a. Percentage of occurrence by each frequency range of F2.

Frequency(Hz)	Number	Percentage(%)
250-300	1	2.8
300-350	1	2.8
350-400	2	5.8
400-450	4	11.4
450-500	4	11.4
500-550	7	20.0
550-600	8	22.9
600-650	5	14.3
650-700	1	2.8
700-750	2	5.8

Table 2b. Percentage of occurrence by each frequency range of F1.

Table (2a) shows that the number of data between 1200 Hz and 1400 Hz reaches the high percentage of 60.0. This frequency range of F2 seems to correspond to the central line of Jones' well known vowel chart. Table (2b) shows that the number of data between 500 Hz and 600 Hz constitutes the percentage of 42.9; in more detail, the range between 550 Hz and 600 Hz is in the higher percentage (22.9%) than that between 500Hz and 550Hz (20.0%).

From the analysis above, we determine the central area, illustrated by the shaded region, where schwa might occur without any effect from neighboring sounds. We regard $ə_1$ in Jones' (1960) as

equivalent to the schwas in the shaded area. From now on, the central part is always shaded as a standard point. When we examine each of the examples, we note the distance between the example and the shaded region as well as its own quality and the position on the chart.

2.3.2. Spectral properties of the schwas ə₁, ə₂ and ə₃

In this subsection, we will observe spectral properties of schwas, and determine their tongue-height and tongue-position. It will follow from the result that the description of the English schwa in previous studies is insufficient. Examining whether Jones' classification is true or not, we pursue an appropriate way to classify the English schwa.

2.3.3. ə₁

Jones divides /ə/ into three variants, represented by ə₁, ə₂ and ə₃. The allophone ə₁ is the typical variant which Jones regards as "the principal member". Eighteen examples of ə₁ are shown in Table 3.

		F1(Hz)	F2(Hz)	F3(Hz)
(3)	"about"	599	1270	2559
(4)	"support"	361	1209	2586
(5)	"American"	560	1240	2480
(6)	"hidden"	471	1521	2563
(7)	"Britain"	354	1400	2394
(8)	"lemon"	435	1267	2762
(9)	"happen"	548	1362	2604
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(17)	"payment"	615	1332	2743
(18)	"famous"	474	1356	2795
(19)	"awaken"	573	1176	2332
(20)	"serious"	529	1770	2924

Table 3. The data of ə₁

These examples show that the values of F1 vary from 273 Hz to 615 Hz and those of F2 from 1151 Hz to 1770 Hz. The divergence of F1 and F2 in frequency is clarified in a visible way when plotted as in Figure 6.

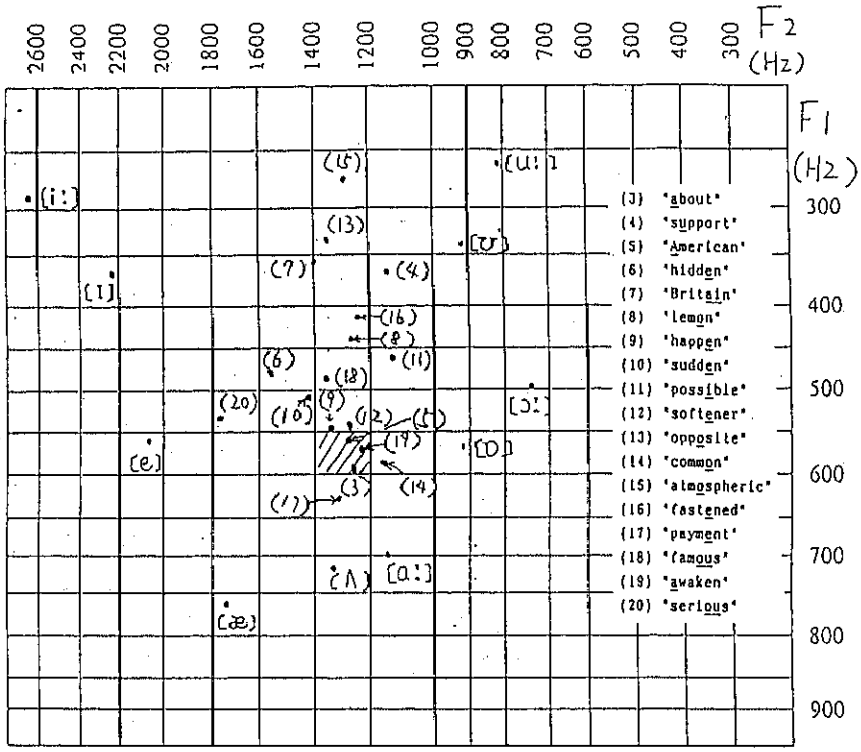

Figure 6. ə₁

Note first that Figure 6 represents that twelve examples of the data above have the F2 values between 1200 Hz to 1400 Hz. This frequency range is almost equivalent to the central line of Jones' vowel chart in Figure 1, on which the allophone ə₁ supposedly occur. Thus, we may regard the twelve schwas as having the same tongue-position as Jone's ə₁.

The remaining six vowels in (4), (6), (10), (11), (14) and (20), deviate from the central line. Three of them, (6), (10) and (20), are shifted forward and the rest, (4), (11) and (14) are retracted backward from the standard shaded area.

The words *hidden*, *sudden*, and *serious* have the schwas shifted forward from the central part of tongue position between 1200Hz and

1400 Hz. The vowel in *serious* is the most advanced variant of all the examples. It seems that the schwa is strongly affected by [ɪ] which is immediately adjacent to the schwa in this example. The second advanced variant of the three is the schwa in *hidden*. This vowel also appears to be influenced by the preceding [ɪ] but since the schwa does not have an immediate contact with [ɪ], unlike the schwa in *serious*, its influence on the schwa may be reduced accordingly. The last example is the schwa in the word *sudden*. The position of the vowel in figure 6 is so close to the central region from 1200Hz to 1400 Hz that we might as well regard it as a typical variant rather than a shifted one. Perhaps the consonant [d] has a relation to this deviation.

The retracted schwas are seen in *support*, *possible* and *common*. The property common to all these examples is that the schwas are surrounded by the two kinds of consonants: one is the consonants produced by lips [p, b, m]; the other is the consonants produced at alveolar position [s, n].

Next consider the values of F1, namely tongue-height (the opening of lower jaw) of the schwa. The values of F1 in Figure 6 do not concentrate into a certain frequency range. The vowels are scattered over the wide range between 326 Hz and 625 Hz. This suggests that schwas in non-word-final positions do not have a typical frequency range of F1. The quality of the schwas extends from [ɯ] to [ʌ] (cf. Henton 1990) even if the range of F2 is restricted to the central region between 1200 Hz to 1400 Hz.

As far as the above examples of $ə_1$ are concerned, it is presumed that they are central vowels as in the previous studies. However, the analysis of F1, which corresponds to the tongue-height, does not enable us to fix the tongue-height of the variant $ə_1$, although this variant is described as having its tongue-height of half-close (Figure 1) or between half-close and half-open (Figures 2-3). This undetermined characteristic of its tongue-height may show that when native speakers perceive the English schwa, they use another different kind of acoustic information other than F1 (tongue-height) and F2 (tongue-position). We will consider what the information is in Section 3.

2.3.4. ə₂

We next turn to the example of ə₂, the schwas adjacent to velar consonants, whose examples are shown in Table 4. The vowel is regarded as a special case by Jones. Gimson (1989) also recognizes the variant as a version of the schwa with the slight raising and retraction of the tongue. The data in the present study contains four examples of ə₂ as listed below.

	F1(Hz)	F2(Hz)	F3(Hz)
(21) "American"	560	1580	2220
(22) "secondary"	410	1669	2298
(23) "awaken"	517	1459	2418
(33) "conquer"	429	1517	2421

Table 4. The data of ə₂

Note that the schwas in Table 4 also appear in the same position as do ə₁ and ə₃. The examples in (21), (22) and (23) occurs in the same environment for ə₁, and the example in (33) for ə₃, namely a word-final schwa. The property common to these four examples is that they adjoin to velars. Jones and Gimson also regard it as crucial to distinguish ə₂ from ə₁ and ə₃.

According to the previous studies, the schwas in Table 4 are raised and retracted versions (cf. Figures 1-3). The schwas in Table 4 would thus occur rightward and upward to the standard shaded area. We, however, see the different behavior of the schwas from this prediction. Observe Figure 7. We first recognize that all the schwas are plotted leftward from the shaded region in the chart. This means that when these vowels are articulated, the tongue is more advanced than in pronunciation of the typical ə₁. We next observe that the schwas in *secondary* and *conquer* are placed upwards to the shaded part but the other examples in *American* and *awaken* have nearer values to the standard area. This suggests that the opening of lower jaw is not always closer than ə₁ when schwas adjacent to velar consonants are articulated contrary to the description of the previous studies.

2.3.5. ə₃

Jones says that ə₃ is the variant which occurs in word-final position. Twelve examples are listed in Table 5.

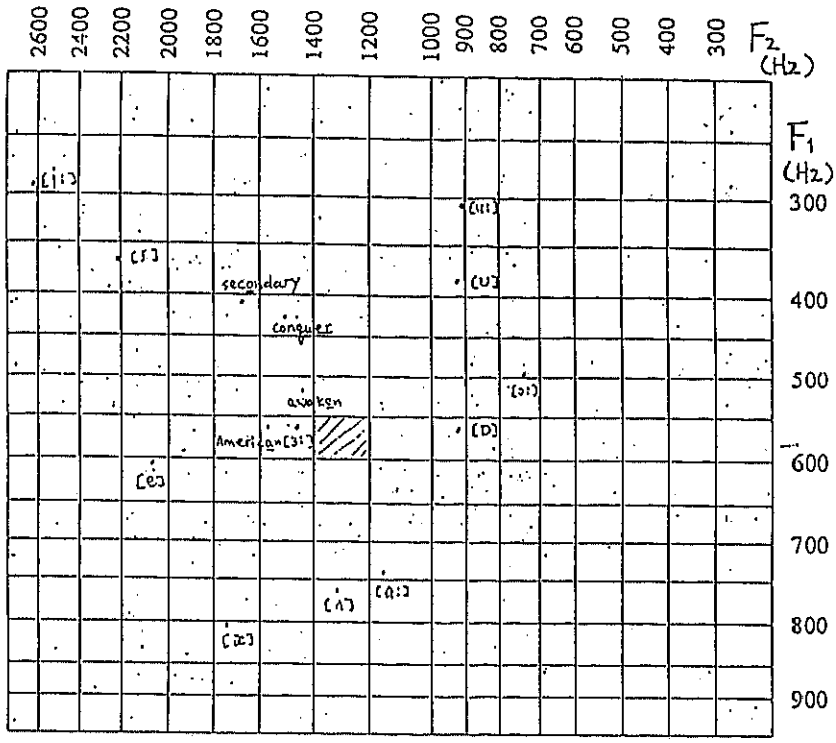

Figure 7. $\partial_{\mathcal{Z}}$

	F1(Hz)	F2(Hz)	F3(Hz)
(24) "leader"	505	1367	2637
(25) "sister	618	1378	2579
(26) "leather"	616	1339	2525
(27) "leisure	656	1587	2522
(28) "pleasure"	586	1534	2515
(29) "catcher"	582	1572	2598
(30) "ladder"	629	1453	2704
(31) "other"	621	1368	2519
(32) "author"	716	1360	2594
(33) "conquer"	429	1517	2421
(34) "softener"	480	1320	2830
(35) "comma"	596	1241	2701

Table 5. The data of $\partial_{\mathcal{Z}}$

The data in Table 5 show that the values of F1 vary in frequency from 429 Hz to 716 Hz and the values of F2 from 1241 Hz to 1587 Hz. Let us visibly observe the divergence of the values in Figure 8.

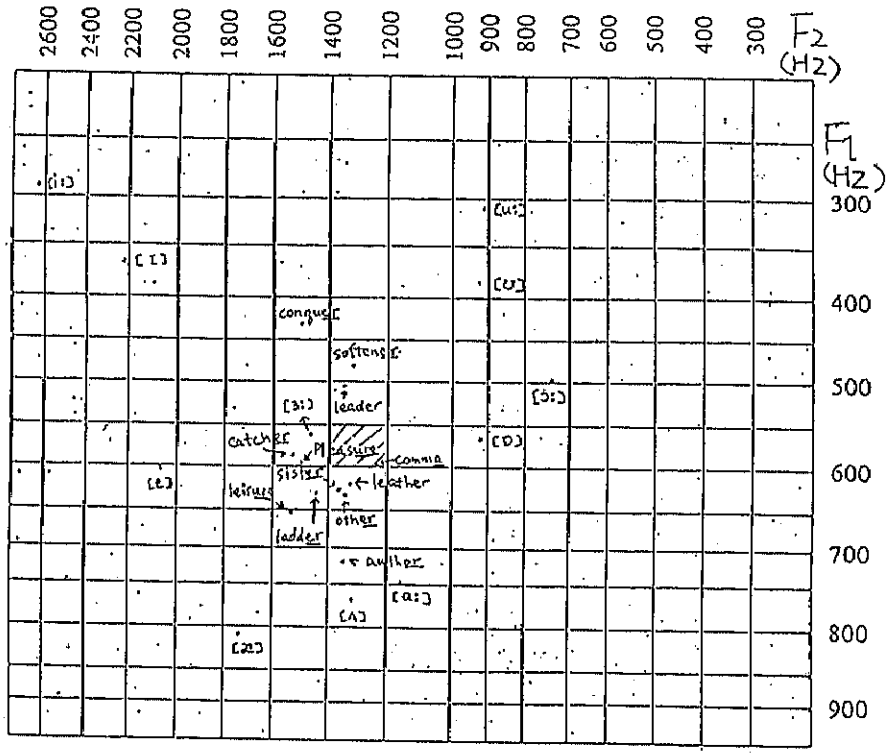

Figure 8. ə₃

As for F2, those of seven examples (*softener*, *leader*, *comma*, *leather*, *sister*, *other* and *author*) are plotted in the central region; their tongue-position in articulation is the same as that of the typical member, ə₁, as described in Jones (1960) and Gimson (1989). Those of the rest (*conquer*, *catcher*, *pleasure*, *ladder* and *leisure*), however, deviate from the central region.

As for F1, on the other hand, those of six examples plotted in Figure 8 have the values in frequency less than 600 Hz. It is important to note these examples because they are the counter examples against Jones' description. Jones says that the word-final schwa, ə₃,

cannot be replaced by the other variants ə₁, and ə₂. According to his remark, the word-final schwas should occur in the part under the line of 600 Hz in Figure 8. However, the six examples in *conquer*, *softener*, *leader*, *catcher*, *pleasure* and *comma* occur in the region over 600 Hz where ə₁ and ə₂ occur but ə₃ should not.

To sum, the acoustic analysis of the schwas in this section has identified the frequency range of F2 between 1200 Hz and 1400 Hz as the central line on Jones' vowel chart (cf. Figure 1). The analysis above has acoustically proved that the English schwa is a central vowel accordingly. However, some schwas deviate from that frequency range. This fact should be explained in some way (cf. Fowler 1981 and Shimada 1994).

The tongue-position of schwas still can vary with adjacent velar consonants. Although Jones and Gimson also remark this fact, the acoustic analysis on the schwas has proven that they wrongly describe the tongue movement of the schwas as backward movement in articulation, which would be illustrated as rightward movement on the chart. In fact the schwas move leftward on the chart, namely in the opposite direction.

Furthermore we have observed that the English schwa does not seem to have a specified frequency range of F1. This acoustic fact is contrary to the intuition and auditory impression of native speakers, which is reflected in Jones' vowel chart (Figure 1). The acoustic facts proves that the English schwa can vary its opening of lower jaw (or tongue-height) in accordance with the environment around it. What factor, then, makes us recognize three variants for the English schwa? We will consider this issue in the next section.

3. An acoustic clue for the cognition of schwa

We have observed in the previous section that the quality of schwa shown by the values of F1 and F2 has the noticeably wide diversity. The range of the diversity is much wider than native speakers intuitively imagined (cf. Jones 1960; Gimson 1989; Wells 1990). Why, then, do native speakers divide /ə/ into three variants? We note here the acoustic aspects of the English schwa. Measuring the ratio of F3 and F2, we discover that each of the variants take its fixed value of F3/F2. We, thus, propose that this value play a significant role in the recognition of the English schwa.

3.1. F1 and F2 value of vowels

It is generally said that quality of vowels can corresponds to F1 and F2 values (cf. Ladefoged 1993). F1 corresponds to tongue-height (or opening of the lower jaw), and F2 corresponds to the tongue-position. The gestalt of F1 and F2 determines the quality of vowels. The correspondence is illustrated by the examples of /i:/, /u:/ and /ɑ:/ in Table 6:

	F1(Hz)	F2(Hz)
/i:/	280	2620
/u:/	320	920
/ɑ:/	740	1180

Table 6. The values of F1 and F2 of /i:/, /u:/ and /ɑ:/

The values of F1 and F2 in the above vowels differ from each other. Both /i:/ and /u:/ are a close (or high) vowel and thus have a close F1 value. In contrast, they have quite different values of F2 because /i:/ is a front vowel, while /u:/ is a back vowel. For /ɑ:/, its F1 and F2 values are distinct from the values of F1 and F2 of /i:/ and /u:/. /ɑ:/ is usually described as a open (or low) and back vowel, but its actual tongue-position is shifted forward relative to /u:/. /ɑ:/, thus, have its larger F2 value than /u:/.

As far as the schwas analyzed in section 2 are concerned, on the other hand, we have observed that their quality is not determined by the values of F1 and F2. This is because /ə/ has a great diversity in F1 value, although this fact is not described in the previous studies. In what follows, we seek for a clue for the cognition of /ə/, noting a characteristic other than F1 and F2.

3.2. F3/F2 value of the English schwa

In this subsection we consider the value of F2 and F3 of English schwas. The examples of $ə_1$ are illustrated in Table 8. This variant is the principal member, i.e., the most typical variety of the English schwa. Thus, if we find some relation between F2 and F3, we can consider the relation as a typical clue of the cognition of the English schwa.

		F1(Hz)	F2(Hz)	F3(Hz)	F3/F2
(1)	[ə]	543	1276	2565	2.01
(2)	[ə]	721	1337	2654	1.98
(3)	"about"	599	1270	2559	2.01
(4)	"support"	361	1209	2586	2.14
(5)	"American"	560	1240	2480	2.00
(6)	"hidden"	471	1521	2563	1.68
(7)	"Britain"	354	1400	2394	1.71
(8)	"lemon"	435	1267	2762	2.17
(9)	"happen"	548	1362	2604	1.91
(10)	"sudden"	510	1422	2778	1.95
(11)	"possible"	461	1153	2513	2.18
(12)	"softener"	545	1310	2530	1.93
(13)	"opposite"	326	1377	2560	1.85
(14)	"common"	592	1151	2680	2.32
(15)	"atmospheric"	273	1286	2748	2.13
(16)	"fastened"	417	1248	2511	2.01
(17)	"payment"	615	1332	2743	2.06
(18)	"famous"	474	1356	2795	2.05
(19)	"awaken"	573	1176	2332	1.98
(20)	"serious"	529	1770	2924	1.35

Table 7. The value of F1-F3 and F3/F2 of ɚ

In Table 7, The values of F3 vary from 2332 Hz to 2924 Hz. Let us here measure the ratio of F3 and F2. As shown in the rightmost column in Table 7, we find out that the value is almost fixed for this variant (the average is 1.96). We ,then, propose that this value play a crucial part in the cognition of the schwa. Judging from the average of these values, the standard value is probably determined to around 2.00. This means that it is a necessary condition for the English schwa that for F2 and F3, F3 represents the value twice as large as that of the F2.

In order to verify the adequacy for the value, we compare the following examples:

	F1(Hz)	F2(Hz)	F3(Hz)	F3/F2
(1) [ə]	543	1276	2565	2.01
(11) "possible"	461	1153	2513	2.18
(15) "atmospheric"	273	1286	2748	2.13

Table 8. The comparison with F3/F2 value among the schwas with different values of F1 and F2

The schwa (1) has its typical values of F1, F2 and F3 respectively, and what is more important, its F3/F2 value is 2.01. The example (15) has the value of F1, and the example in (11) the value of F2. Measuring the value of (11) and (15), we find out that these two schwas have close values to that of (1). Thus, both (11) and (15) are recognized as $ə_1$.

We next consider $ə_2$. Since this vowel displays their characteristic in quality as we have seen in Section 2, we predict that the value of F3/F2 of $ə_2$ exhibits a great difference from that of $ə_1$.

	F1(Hz)	F2(Hz)	F3(Hz)	F3/F2
(6) "American"	560	1580	2220	1.40
(14) "secondary"	410	1669	2298	1.39
(24) "conquer"	429	1517	2421	1.59
(35) "awaken"	517	1459	2418	1.66

Table 9. The value of F1-F3 and F3/F2 of $ə_2$

In Table 9, all the values of F3/F2 in the above examples are smaller than 2.00; the average is 1.51 because of the effect of [k]. From this fact, we propose that the F3/F2 value of $ə_2$ be 1.50, and this value be a significant clue to the cognition of $ə_2$.

Finally let us turn to $ə_3$. This variant is regarded as a central vowel as $ə_1$ is. We thus predict that the F3/F2 value of $ə_3$ is very close to that of $ə_1$. Consider as follows:

	F1(Hz)	F2(Hz)	F3(Hz)	F3/F2
(24) "leader"	505	1367	2637	1.92
(25) "sister"	618	1378	2579	1.87
(26) "leather"	616	1339	2525	1.88
(27) "leisure"	656	1587	2522	1.58
(28) "pleasure"	586	1534	2515	1.63
(29) "catcher"	582	1572	2598	1.65

(30) "ladder"	629	1453	2704	1.86
(31) "other"	621	1368	2519	1.84
(32) "author"	716	1360	2594	1.90
(33) "conquer"	429	1517	2421	1.59

Table 10. The value of F1-F3 and F3/F2 of $ə_3$

Based on the F3/F2 value, we divide the examples in Table 10 into two groups: those having a close value to that of $ə_1$(the average is 1.94); those in (27), (28), (29) and (37), which are next to [ʒ] or [tʃ], have a F3/F2 value smaller than 2.00 (the average is 1.61). Recall here that we consider $ə_2$ as distinct from $ə_1$ even if both of them occur in the same environment, namely in non-word-final positions, because $ə_2$ is in the vicinity of velars. As in the case of $ə_3$, too, we regard the examples in (27), (28), (29) and (37) as different from the othes. Thus we propose that the F3/F2 value of $ə_3$ be 2.00.

4. Conclusion

We have investigated the quality of the English schwa based on its frequency values to answer the two following questions:

a. Is it possible to divide /ə/ as three variants as in previous studies with its tongue-height and tongue-position?
b. What is the properties to determine each of the /ə/ variants?

The answer to (a) is no. The analysis of F1 and F2 have shown that /ə/ has no fixed F1. This suggests that the tongue-height varies depending on the environment around /ə/. As for F2, on the other hand, its value approximately converge in the frequency range between 1200 and 1400 Hz. This is because /ə/ is articulated with the fixed tongue-position (i.e., central). Therefore, we conclude that /ə/ is categorized as a central vowel but it is not divided into three variants with tongue-height and tongue-position proper to each of them.

The answer to (b) is the F3/F2 value. Each of the variants of /ə/ has its own value: for $ə_1$, the value is estimated at 2.00; 1.50 for $ə_2$; 2.00 for $ə_3$.

Although the possibility for the traditional articulatory classification of /ə/ is denied, we should draw attention to the fact that some researchers such as Jones have an intuition that /ə/ is divides into three variants as seen in Section 1. The answer to (b) seems support their intuition. We have considered the value of F3/F2, which differs among the variants described in previous studies. From this fact, We have proposed that the F3/F2 value play an crucial role role in the cognition of /ə/, and that the typical value is 2.00 for ə$_1$. The validity of the value should be confirmed in future research from various viewpoints.

Notes

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[1] Using such instruments, Fowler (1981) and Shimada (1994) analyze the assimilatory effect of vowels adjacent to schwa in detail.

[2] This vowel [ɯ] occurs in Japanese words such as *ku* "pain" .

[3] This schwa is pronounced alone in Shimaoka and Wells(1992).

[4] This schwa is pronounced alone in Fletcher (1990).

[5] These formant values of the vowels, which function as cardinal vowels, are cited from Gimson (1989).

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