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# Cross-generational Change of /*o*/ and /*u*/ in Seoul Korean II: Spectral Interactions in Normalized Vowel Space*

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**ABSTRACT**

This is a follow-up study on Han and Kang (2013) which argued that the Euclidean distances between /o/ and /u/ in Seoul Korean decreased in the first syllable position as speakers were among younger female speakers but not for male speakers, whereas in the second syllable position both gender groups showed a cross-generational decreasing effect of the Euclidean distance between /o/ and /u/.

This study normalized the same data in Han and Kang (2013) which measured 12 speakers (six males and six females) for each Age group and investigated the spectral changes vowels /o/ and /u/ between age and gender, using the log-mean normalized statistical results. This study also examined overlap fraction values generated in SOAM 2D (F1 x F2) (cf. Wassink, 2006), which may also indicate the proximity of two vowels in question.

The results showed that /o/ and /u/ vowels were making closer with /o/ raising for female speakers in $V_1$ and $V_2$ positions but only in the $V_2$ position for male speakers. That is, females led the upward movement of peripheral /o/ vowel, just like the raising of ‘e’ and ‘o’ in New York City (Labov, 1991). The results also showed that younger speakers used a rather narrow vowel space for the vowels. This also contributed to the proximity of the vowels /o/ and /u/, resulting in rather large overlap fraction values for younger speakers between these two vowels.

**Keywords: spectral changes, Seoul Korean /o, u/ vowels, log-mean normalized statistical results, overlap fraction values**

## 1. Introduction

The observation that a pair of vowels, /o/ and /u/, in Korean are quite close to each other has been reported by many studies over the last 20 years. Interestingly, a close examination of these studies shows that /o/ and /u/ are close but differently positioned to each other in the F1 x F2 vowel plane depending on when the observation was made.

In Yang (1996), the vowels /o/ and /u/ were shown to be close but still distinguished from each other mostly by F1 differences in the vowel space: That is, for males the mean F1 and F2 values were 369 Hz and 981 Hz for /u/ and 453 Hz and 945 Hz for /o/, respectively. For females, the mean F1 and F2 values were 422 Hz and 1021 Hz whereas they were 499 Hz and 1029 Hz, respectively. There was larger F1 difference than F2 difference between /o/ and /u/ for both male and female speakers.

Interestingly, a recent study like Moon (2006) showed that these two vowels were still very close among his subjects who were in their 20s, but with interesting differences from the study by Yang (1996): the vowels /o/ and /u/ had noticeable differences in F2 dimension if speakers were female, but in F1 dimension if speakers were male. That is, the results of Moon (2006) clearly showed gender difference in the production of vowels /o/ and /u/.

Previous sociolinguistic studies have argued that women are most often the innovators of the systematic sound changes in

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most of the linguistic changes in progress (cf. Labov, 1991; Eckert, 1989; Di Paolo, 1988; Chambers & Hardwick, 1985 among others).

Considering the time gap and gender-related differences between Yang (1996) and Moon (2006), Han and Kang (2013) suspected that there might be vowel change across age and gender, and thus examined three age groups of speakers of different gender: 20’s (M/F), 30’s (M/F) and 40’/50’s (M/F). For the investigation of the change in the vowel space, they first presented the vowel distributions of Seoul Korean in traditional F1 x F2 vowel space and then calculated the Euclidean distances between /o/ and /u/ using the raw F1 and F2 values across age and gender. They showed that the cross-generational change of /o/ and /u/ was most evident in female speakers and in the unfocused non-initial syllable position.

In particular, Han and Kang (2013) showed that in the first syllable position of the two-syllable word (V1, hereafter), the Euclidean distances between /o/ and /u/ have decreased as speakers were getting younger for female speakers but not for male speakers and that in the second syllable position of the two-syllable word (V2, hereafter), both gender groups showed cross-generational decreasing effects of Euclidean distance between /o/ and /u/.

The analysis in Han and Kang (2013), however, did not show in what directions－raising or lowering and/or fronting or backing－the vowels /o/ and /u/ have approximated to each other across the age and gender groups. Thus, to further investigate the change of /o, u/ vowel distributions in terms of spectral features across the age and gender groups, this study shows the normalized vowel distributions within log F1 x F2 vowel space, normalized statistical results of female and male speakers’ /o, u/ vowels, and then discusses the results of overlap calculations generated in Spectral Overlap Assessment Measures (SOAM) 2D (F1 x F2).

## 2. Method

Participants, Stimuli and Procedure in this paper were the same as those in Han and Kang (2013) as this paper used the same data in that paper.

### 2.1 Participants

Thirty-six Seoul dialect speakers participated in the experiment. They were categorized into three age groups: 20’s, 30’s, and 40’s/early 50’s. They will be referred to as Age20, Age30 and Age40 groups, respectively, in this paper. There were 12 speakers (6 males and 6 females) in each group. None reported any hearing or speaking problem.

### 2.2 Stimuli

Eight Korean monophthongs such as /ɑ, e, ɛ, i, o, u, ɨ, ʌ/ were recorded for this experiment, though the vowels of interest were /o/ and /u/. They were produced in a bisyllabic pseudoword with a $V_1CV_2$ structure: $V_1$ or $V_2$ was one of the eight Korean vowels and the consonant C was one of /p, t, k/. The purpose of including all eight vowels and three consonantal places was to use vowel-extrinsic normalization procedure and to neutralize the coarticulatory effects of consonants on adjacent vowels. The frame sentence was ‘cʰəncʰənhi ___ hasejo’ (‘Please do (say) ____ slowly’).

### 2.3 Procedure

Each participant was individually recorded in a sound-proof booth with a Shure KSM10 microphone and a Tascam (HD-P2) cassette tape recorder. The recorded tokens were digitized in Praat at a sampling rate of 44.1 kHz and saved as 16-bit computer audio files to be used in the acoustic measurements. The F1 and F2 values were automatically extracted, using Praat and were hand-corrected when necessary. The total number of tokens for analysis was 6912 (3 age groups (Age20, Age30, Age40) x 12 speakers (6 males, 6 females) x 192 tokens (8 $V_1$ x 3 intervening consonants x 8 $V_2$)).

### 2.4 Normalization

For the normalizaion method, we adopted vowel-extrinsic normalization procedure in Wassink (2006) and Nearey (1977), which suppresses the effects of interspeaker variation due to physiological factors and preserves the effects of sociolinguistic language variation. The procedure was as follows. First, the raw F1 and F2 values of all eight vowels were log-transformed. Second, for each participant, the grand means of log F1 and log F2 values of all eight vowels of each speaker were calculated, which represented the center of the speaker’s vowel space (0, 0). Third, the difference scores were calculated for each vowel token by subtracting grand mean log F1 and log F2 from log F1 and log F2 of each vowel token, respectively. Each data point was then expressed relative to the center of each speaker’s vowel space (0, 0).

## 3. Results

### 3.1 Normalized Vowel Chart

Figures 1 and 2 show the vowel charts with normalized vowels in $V_1$ position for male and female speakers. Both vowel charts show that Age20 groups occupied less peripheral positions than the other age groups regardless of gender. In addition, it is evident that female speakers greatly reduced F1 differences between /o/ and /u/ as they were getting younger.

Figures 3 and 4 present the cross-generational normalized vowel charts at $V_2$ position for male and female speakers, respectively. Both vowel charts show that vowels in $V_2$ position occupied less peripheral positions than those in $V_1$ position regardless of gender. Like in $V_1$ position, Age20 groups occupied less peripheral positions than the other age groups.

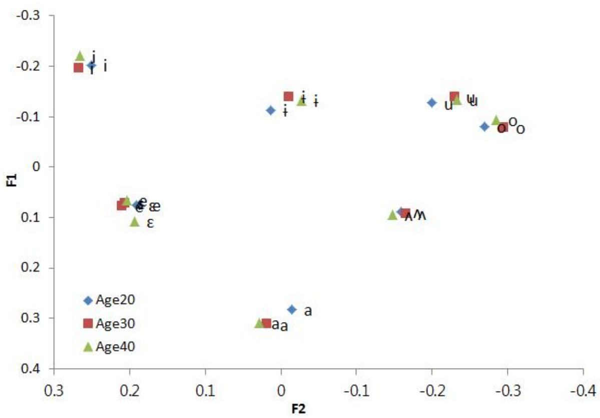


Figure 1. Cross-generational vowel dispersion patterns for Korean male speakers in $V_1$ position.

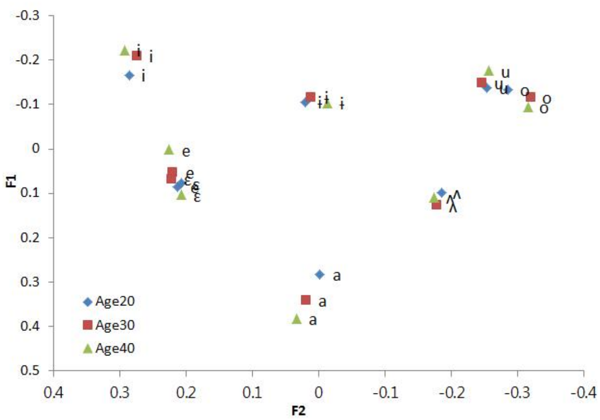


Figure 2. Cross-generational vowel dispersion patterns for Korean female speakers in $V_1$ position.

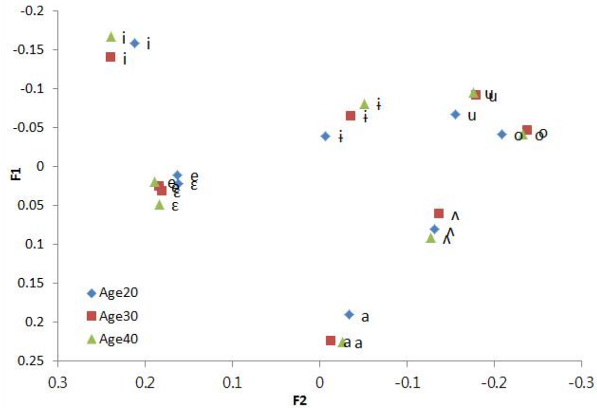


Figure 3. Cross-generational vowel dispersion patterns for Korean male speakers in $V_2$ position.

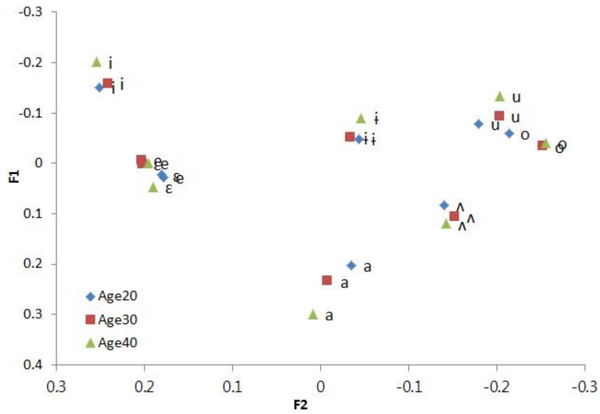


Figure 4. Cross-generational vowel dispersion patterns for Korean female speakers in $V_2$ position.

### 3.2 Statistical Results of Vowel-extrinsic Normalization

Tables 1-4 present means and standard deviations for the log-mean normalized F1 and F2 values of male and female groups in $V_1$ and $V_2$ positions, respectively. Let us first consider log-mean normalized F1 and F2 values in $V_1$ position.

Table 1. Log-mean normalized F1 and F2 values of male speakers in $V_1$ position

| Vowel | Age20 | Age30 | Age40 |
|---|---|---|---|
| /o/ | | | |
| log F1 | -0.080 | -0.078 | -0.093 |
| (s.d.) | (0.021) | (0.036) | (0.060) |
| log F2 | -0.270 | -0.295 | -0.285 |
| (s.d.) | (0.030) | (0.041) | (0.031) |
| /u/ | | | |
| log F1 | -0.127 | -0.139 | -0.134 |
| (s.d.) | (0.052) | (0.037) | (0.057) |
| log F2 | -0.200 | -0.230 | -0.233 |
| (s.d.) | (0.041) | (0.056) | (0.060) |

Log-mean normalized values of /o/ in V1 position (averaged across all speakers) for male Age20, Age30 and Age40 groups were –0.080, -0.078, and –0.093, respectively for log F1, and -0.270, -0.295, and -0.285 for log F2, respectively. These values represent mean token deviations from the center of each age group's vowel space. Since all spaces were centered at (0.0), /o/ data of male Age20 group were produced at slightly lowered articulatory location along the height (F1) dimension in that system compared to /o/ data of Age40 group: normalized F1 values are somewhat smaller[3)] along the height dimension. Along the front-back (F2) dimension, male Age20 /o/ data moved slightly toward center(front) compared to Age30 and Age 40 /o/s: normalized F2 values were slightly smaller than those of Age 30 and Age40 /o/'s.

Log-mean normalized values of /u/ for male Age20, Age30 and Age40 groups were –0.127, -0.139, and -0.134 in log F1 dimension, respectively, and –0.200, -0.230, and -0.233 in log F2 dimension, respectively. F1 values of these age groups showed that the male Age20 /u/ data were slightly lower along the height (F1) dimension than the other age groups while along the front-back (F2) dimension, they moved somewhat toward the center(front) compared to those of male Age40 group.

In summary, vowels /o/ and /u/ in $V_1$ position got slightly lowered along the high-low dimension and moved somewhat to the direction of center(front) as male speakers were getting younger.

Table 2. Log-mean normalized F1 and F2 values of female speakers in $V_1$ position

| Vowel | Age20 | Age30 | Age40 |
|---|---|---|---|
| /o/ | | | |
| log F1 | -0.134 | -0.117 | -0.095 |
| (s.d.) | (0.030) | (0.028) | (0.034) |
| log F2 | -0.286 | -0.320 | -0.316 |
| (s.d.) | (0.037) | (0.037) | (0.053) |
| /u/ | | | |
| log F1 | -0.139 | -0.149 | -0.176 |
| (s.d.) | (0.035) | (0.036) | (0.050) |
| log F2 | -0.254 | -0.247 | -0.257 |
| (s.d.) | (0.045) | (0.040) | (0.075) |

3) In this paper, we will say "smaller" if the distance between the normalized vowel value of one group and the center (0, 0) is shorter in a given dimension than that of another group, and "larger" if that distance is longer.

For female Age20, Age30 and Age40 groups, log-mean normalized F1 values of /o/ in $V_1$ position were -0.134, -0.117 and -0.095, respectively and log-mean normalized F2 values of /o/ were -0.286, -0.320, and -0.316, respectively. This means that female /o/ data was raised in articulatory vowel space along the height (high-low) dimension as speakers were getting younger since normalized F1 values for /o/ were progressively larger in the order of Age40, Age30 and Age20. Along the front-back dimension /o/ data of Age20 group moved further front(center) in that system since the normalized F2 value was smaller than those of Age30 and Age40 groups .

Log-mean normalized values of /u/ for female Age20, Age30 and Age40 groups were -0.139, -0.149 and -0.176 for log F1, respectively and -0.254, -0.247, -0.257 for log F2, respectively. It was shown that female /u/ data got lowered as speakers were getting younger along the height (high-low) dimension since normalized F1 values for /u/ were progressively getting smaller in the order of Age40, Age30 and Age20. Along the front-back dimension little change occurred across different age groups. In sum, vowels, /o/ and /u/, moved toward the opposite directions in the height dimension-- /o/ was raised while /u/ was lowered as speakers are younger-- while along the front-back dimension, /o/ moved more toward the direction of front while /u/ stayed more or less at the same position in the vowel space.

Table 3. Log-mean normalized F1 and F2 values for male speakers in $V_2$ Position

| Vowel | 20 | 30 | 40 |
|---|---|---|---|
| /o/ | | | |
| log F1 | -0.042 | -0.046 | -0.053 |
| (s.d.) | (0.028) | (0.040) | (0.056) |
| log F2 | -0.209 | -0.238 | -0.231 |
| (s.d.) | (0.047) | (0.051) | (0.058) |
| /u/ | | | |
| log F1 | -0.067 | -0.092 | -0.106 |
| (s.d.) | (0.046) | (0.052) | (0.055) |
| log F2 | -0.156 | -0.180 | -0.174 |
| (s.d.) | (0.044) | (0.056) | (0.068) |

For male speakers in $V_2$ position, log-mean normalized values of /o/ data for Age20, Age30 and Age 40 were -0.042, -0.046 and -0.053 in log F1 dimension, respectively and -0.209, -0.238, and -0.231 in log F2 dimension, respectively. Vowel /o/ got slightly lowered along the height (high-low) dimension as speakers were younger since its normalized F1 values got progressively smaller in the order of Age40, Age30 and Age20. Along the front-back dimension, smaller normalized F2 value of Age 20 /o/ indicated more centralized (fronted) articulation than Age30 and Age40 /o/s.

Log-mean normalized values of /u/ in the same position for Age20, Age30 and Age 40 were -0.067, -0.092 and -0.106 in log F1 dimension and -0.156, -0.180, and -0.174 in log F2 dimension, respectively. Log F1 values showed that /u/ got lowered considerably along the height (F1) dimension the younger speakers were. Along the front-back dimension /u/ of Age20 group moved further front compared to /u/s of Age30 and Age40 groups as its smaller normalized F2 value clearly indicated. That is, both /o/ and /u/ were lowered in the height dimension but considerably more so for /u/ than /o/.

We suggest that there was, in fact, a raising of /o/ for males speakers in this position. The raising of /o/ was not apparent due to the lowering/centralizing of peripheral vowels like /o/ and /u/ as speakers were younger. The magnitude of /o/ raising for male speakers was comparatively smaller and thus cancelled out with the lowering of /o/ due to the lowering/centralizing of peripheral vowels like /o/ and /u/. As a result, vowel /o/ did not show much movement in this position.

Table 4. Log-mean normalized F1 and F2 values for female speakers in $V_2$ Position

| Vowel | 20 | 30 | 40 |
|---|---|---|---|
| /o/ | | | |
| log F1 | -0.060 | -0.034 | -0.041 |
| (s.d.) | (0.038) | (0.056) | (0.047) |
| log F2 | -0.214 | -0.253 | -0.256 |
| (s.d.) | (0.060) | (0.071) | (0.057) |
| /u/ | | | |
| log F1 | -0.079 | -0.094 | -0.134 |
| (s.d.) | (0.050) | (0.069) | (0.057) |
| log F2 | -0.180 | -0.203 | -0.204 |
| (s.d.) | (0.058) | (0.053) | (0.053) |

For female Age20, Age30 and Age40 groups, log-mean normalized values of /o/ in $V_2$ position were -0.060, -0.034, and -0.041 in log F1 dimension, respectively and -0.214, -0.253, and -0.256 in log F2 dimension, respectively. We could see that /o/ for female Age20 group was raised along the height (F1) dimension as its normalized F1 value was larger than those of Age30 and Age40. Along the front-back dimension Age20 /o/ data moved further front(center) in that system compared to Age30 and Age40 /o/s.

Log-mean normalized values of /u/ in $V_2$ position for Age20, Age30 and Age40 were -0.079, -0.094, and -0.134 in log F1 dimension, respectively and -0.180, -0.203, and -0.204 in log F2 dimension, respectively. The data showed that female /u/ got considerably lowered along the height dimension as the normalized F1 values for /u/ got considerably smaller the younger speakers were. Along the front-back dimension Age20 /u/ data moved somewhat toward the front in that system compared to Age30 and Age40 /u/s.

In short, the data showed that as female speakers are getting younger, /o/ and /u/ moved toward the opposite directions in the height dimension which was also observed in the $V_1$ position: /o/ data were raised while /u/ data were lowered as speakers were younger in age. Along the front-back dimension, /o/ data moved further front than /u/ data did. The same trend was observed for /o/ in the $V_1$ position of female speakers.

Conclusively, as speakers were younger in age, /u/ data were produced at the lower position in the height dimension and more at the front in the front-back dimension within the system's vowel space. For this, we suggested that young speakers had the tendency to use less peripheral positions for the production of vowels.

For /o/, a somewhat different trend was observed depending on the gender. As the speakers were younger, male speakers produced /o/ at slightly lower articulatory locations whereas female speakers produced /o/ more at the higher articulatory locations in the vowel space: /o/ was raised while /u/ was lowered for female speakers while both /o/ and /u/ were lowered for male speakers.

However, we also noted that /o/ in the $V_2$ position of male speakers was in fact raised with a small magnitude, and that this small /o/-raising effect was not apparent as the raising of /o/ was cancelled out with the large lowering of peripheral vowels like /o/ and /u/ in this position.

### 3.3 Overlap Fraction Values

Data in Tables 1-4 showed how close vowels /o/ and /u/ are to each other in each spectral dimension. In this section, we will consider how different spectral features interact in the vowel distribution by examining the overlap fraction values of the relevant vowels in two-dimensional space using SOAM-3D (Wassink, 2006)[4]. SOAM-3D produces overlap fractions

4) Overlap fractions values and the diagrams were produced using VOIS-3D software by Wassink. We did not use the

between two vowels, using statistical properties of normalized estimates of vowel formants, F1 and F2. Wassink (2006) assumed that overlap fraction values may indicate the proximity of the two vowels in question, though she also noted the shortcomings of her approach.

Overlap between two vowel distributions is calculated by the area of the region of overlap by ellipses which are shown as best-fit ellipses. Ellipse plots in Figures 5-8 show the proximity between /o/ and /u/ in the F1 X F2 plane for each age and gender group in $V_1$ and $V_2$ positions.

As we could see in Figures 5-8, ellipse plots roughly showed the featural changes two vowels /o, u/ underwent across the gender and age groups. For example, ellipse plots in the $V_1$ position for male speakers (Figure 5) showed that data /u/ had undergone considerable fronting while data /o/ showed no such change as speakers were younger. A similar phenomenon was observed for male speakers in the $V_2$ position.

Ellipse plots for /o/ and /u/ in the $V_1$ position for female speakers (Figure 6) showed that a large difference between /o/ and /u/ in F1 dimension was progressively disappearing as speakers were becoming younger. A similar phenomenon was observed for /o/ and /u/ for female speakers in the $V_2$ position.

The overlap fraction values resulting from the ellipse model by Wassink (2006) were presented in Table 5. Let us examine whether these values well represented the proximity of /o, u/ in Korean. Let us begin with the vowel pairs /o, u/ of Age20 and Age30 groups.

First, let us compare overlap fraction values of different age groups in the same gender and the same V position. The overlap fractions values of male Age20 and Age30 were 49% and 47% in $V_1$ position and 84% and 60% in $V_2$ position, respectively. For female Age20 and Age30, the percentage overlaps were 90% (Age20) vs. 38% (Age30) in the $V_1$ position and 84% (Age20) vs. 60% (Age30) in the $V_2$ position. That is, Age20 group showed larger overlap fraction values between /o/ and /u/ than Age30 group of the same gender in the same position. As younger speakers were believed to lead the sound change, the overlap fraction values seemed to bear out this observation well.

Secondly, let us compare overlap fraction values of the different genders of the same age groups in each vowel position. The overlap fraction values were 90% (female) vs. 49% (male) in the $V_1$ position and 84% (female) vs. 66% (male) in the $V_2$ position for Age 20 group, and 38% (female) vs. 47% (male) in the $V_1$ position and 60% (female) vs. 58% (male) in the $V_2$ position for Age30 group. Sociolinguists have shown that female speakers would lead the sound change and the results of overlap fraction values seemed to reflect this trend as well: Female speakers showed larger overlap fraction values than male speakers of the same age group in the same linguistic position. The exception was Age30 group in the $V_1$ position: 38% (female) vs. 47% (male).

third factor, duration, for this study.

Table 5. Overlap fractions values between /o/ and /u/

| | | | |
|---|---|---|---|
| | $V_1$ position | | |
| Male | Age20 | Age30 | Age40 |
| o ~ u | 49% | 47% | 79% |
| | $V_2$ position | | |
| | Age20 | Age30 | Age40 |
| o ~ u | 66% | 58% | 62% |
| | $V_1$ position | | |
| Female | Age20 | Age30 | Age40 |
| o ~ u | 90% | 38% | 53% |
| | $V_2$ position | | |
| | Age20 | Age30 | Age40 |
| o ~ u | 84% | 60% | 41% |

Thirdly, let us compare overlap fraction values between /o/ and /u/ of the same age and gender groups in different vowel positions: 66% ($V_2$) vs. 49% ($V_1$) for male Age20, 58% ($V_2$) vs. 47% ($V_1$) for male Age30, 84% ($V_2$) vs. 90% ($V_1$) for female Age20 and 60% ($V_2$) vs. 38% ($V_1$) for female Age30. For each group, overlap fraction values were larger in the less focused $V_2$ position than in the focused $V_1$ position except for females Age20 group: 84% ($V_2$) vs. 90%($V_1$).

In summary, it seems that overlap fraction values between /o/ and /u/ in Seoul Korean well reflected the sound change that were occurring among different age and gender groups with a couple of exceptions.

Overlap fraction values of Age40 group, however, did not well reflect the sociolinguistic trend: Overlap fraction values of Age40 was larger than those of Age30 except female $V_2$ position. For example, in the $V_1$ position the male Age40 group showed a larger percent overlap (79%) than Age30 group (47%).

The unexpected results were mainly due to large vowel space Age40 group used for vowels. In particular, they used peripheral

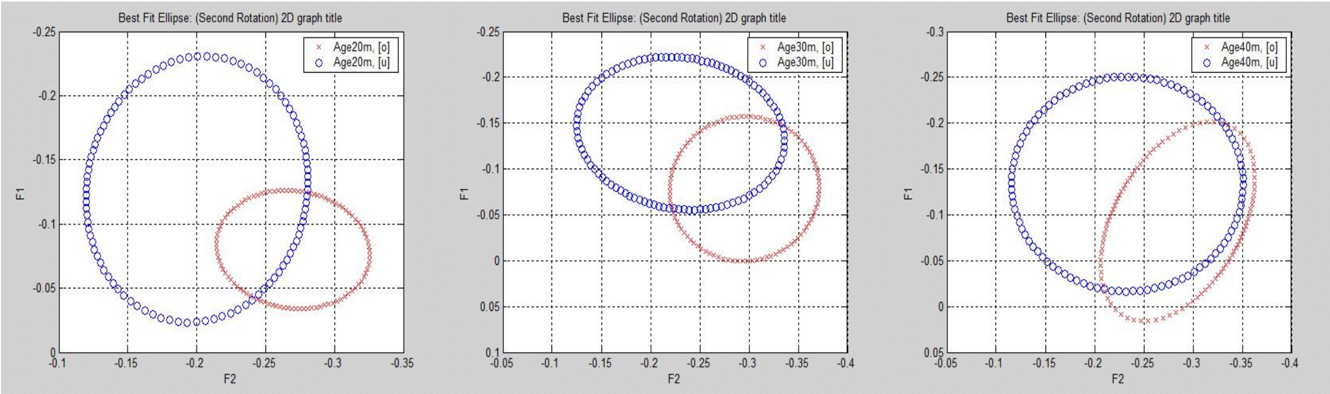


Figure 5. Ellipse plots for /o/ and /u/ in $V_1$ position for male Age20, Age30 and Age40 groups

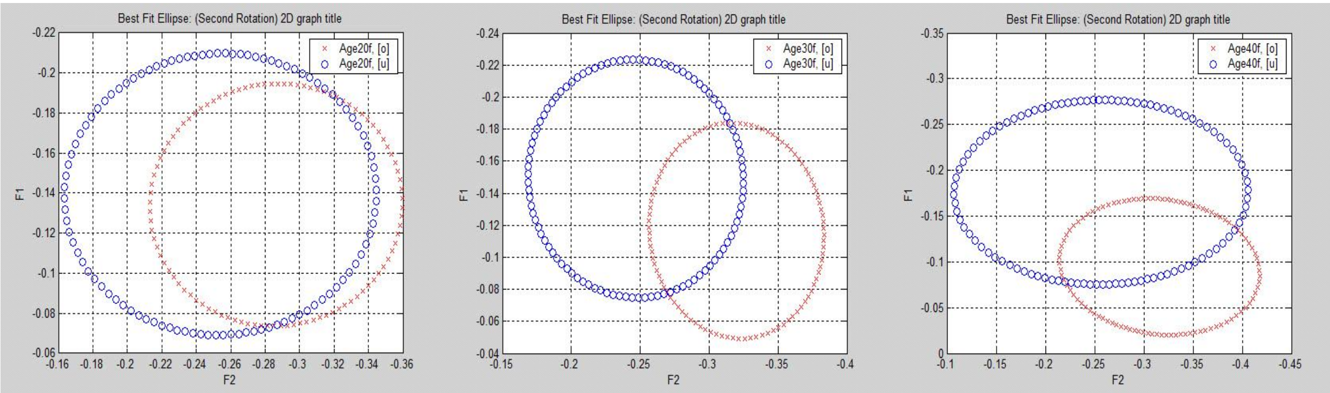


Figure 6. Ellipse plots for /o/ and /u/ in $V_1$ position for female Age20, Age30 and Age40 groups

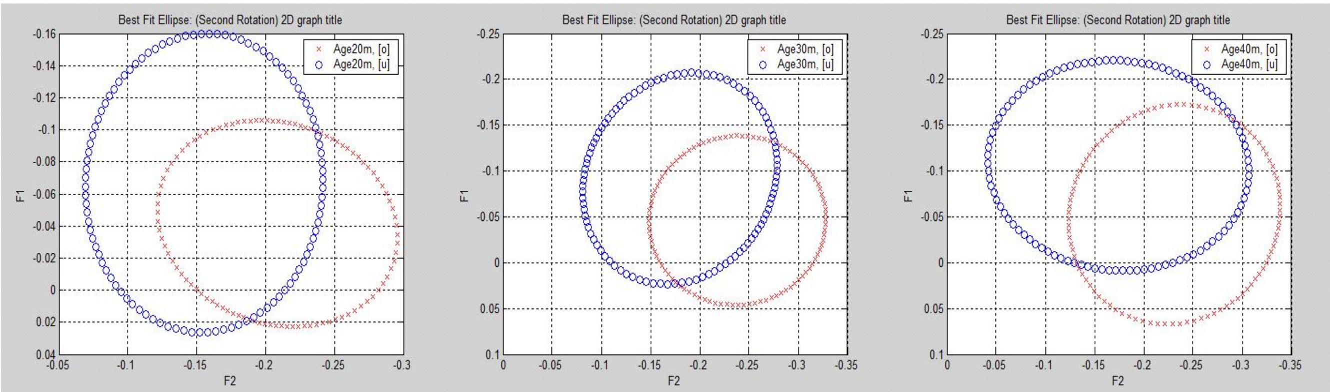


Figure 7. Ellipse plots for /o/ and /u/ in $V_2$ position for male Age20, Age30 and Age40 groups

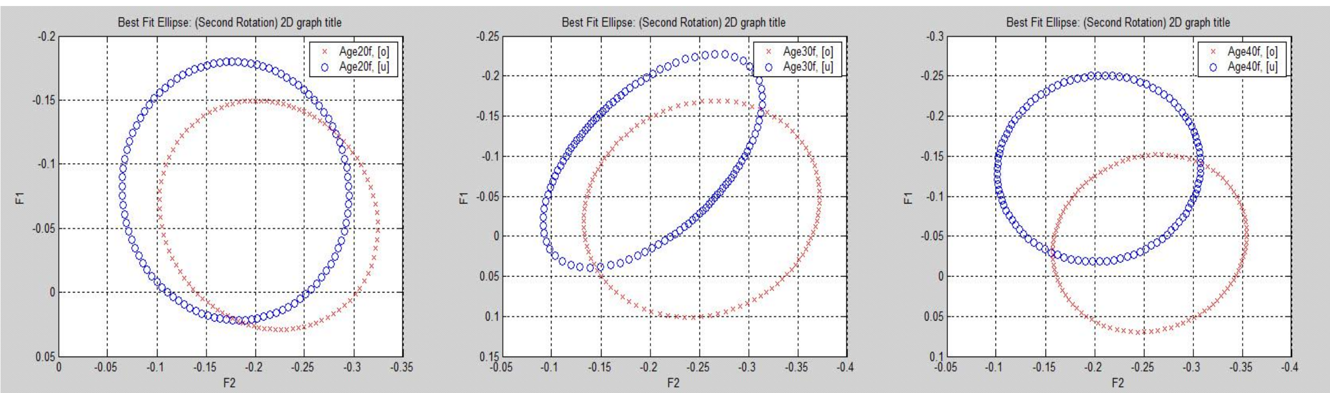


Figure 8. Ellipse plots for /o/ and /u/ in $V_2$ position for female Age20, Age30 and Age40 groups

vowel space for peripheral vowels like /o/ and /u/, which allowed comparatively large F1 and F2 frequency ranges for vowels /o/ and /u/. This resulted in large inter-speaker variability for the Age40 group than other Age groups: some speakers used mainly F1 differences to distinguish /o/ from /u/ and others F2 differences for the same purpose, resulting in large standard deviations shown in Tables 1-3. Since the ellipses were based on the means and the standard deviation of the means (the edge is 2 standard deviations), a large standard deviation may result in large overlap fraction values between two vowels if the means of the relevant vowels were very close.

Therefore, if there was a big difference in the values of the standard deviation, it seemed difficult for overlap fraction values of two vowels to solely show the proximity of the two vowels.

## 4. Discussion

The purpose of this study was to understand how /o, u/ vowel distribution had developed across age and/or gender, especially whether there was any consistent direction (raising/lowering and/or fronting/backing) in the vowel change. To answer these questions, this study applied to the data in Han and Kang (2013) the methods that utilized speaker-extrinsic log-mean normalized statistics (Nearey, 1977) and SOAM-2D by Wassink (2006).

The log-mean normalized data analysis in section 3.2 showed that changes indeed occurred to /o, u/ vowel distribution with age and gender difference: /o/ and /u/ were produced more at the central articulatory locations in the acoustic vowel space by younger speakers regardless of the gender. That is, younger speakers used a rather narrow vowel space for the vowel distribution, avoiding the production of vowels in the peripheral positions.

Gender differences were also observed: young female speakers raised vowel /o/ while young male speakers did not. Specifically, for young female speakers, movements toward the opposite directions by /o/ and /u/ almost erased F1 differences between them, resulting in a short Euclidean distance between them (cf. Han and Kang, 2013) in the $V_1$ and $V_2$ positions. Young male speakers, on the other hand, seemed to take a different way to shorten the distance between /o/ and /u/ in the $V_2$ position: Both /o/ and /u/ got lowered in the $V_2$ position for young male speakers but the vowel /o/ was lowered considerably less than vowel /u/, resulting in two vowels' being close to each other.

We would like to suggest that there was in fact /o/ raising for young male speakers in $V_2$ position as well but with comparatively small magnitude. This /o/ raising was concealed on the surface since its relatively small magnitude was erased by a large lowering of peripheral vowels like /o/ and /u/ caused by the centralized vowel space for younger speakers. The /o/ raising for young male speakers in the $V_2$ position, however, can be observed by the fact that the vowel /o/ was lowered considerably less than the vowel /u/. We conclude therefore that there was /o/ raising for female speakers in $V_1$ and $V_2$ positions and for male speakers, in $V_2$ position.

In section 3.3, we examined the overlap fraction values for Age20 and Age30 groups. The overlap fraction analysis showed that /o/ and /u/ showed larger overlap fraction values for younger speakers, female speakers and unfocused $V_2$ positions. We also considered why Age40 groups had unexpectedly large overlap fraction values.

In conclusion, the results showed that women were in advance of men in the on-going approximation of /o/ and /u/ with the raising of /o/: Females showed /o/ raising in V1 and V2 positions whereas males showed /o/ raising only in V2 position, which argued that females were likely to lead the vowels change as in the upward movement of peripheral vowels such as the raising of ‘e’ and ‘o’ in New York City[5] (Labov, 1991). The vowel change, namely /o/-raising, also seems to agree with the general vowel distribution of languages. Languages with the three vowel system often adopt /i, a, u/ without mid vowels whereas languages with the five vowel system frequently adopt /i, e, a, o, u/ with mid vowels (Ladefoged and Maddieson, 1996).

In a future study, we will investigate whether considerable confusion between /o/ and /u/ occur in perception as well.

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5) For our speculation why women lead the vowel change, see Han and Kang (2013).

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