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Speech Production and Perception of Heritage Speakers of Korean

A thesis submitted in partial satisfaction

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by

Eun Hwa Lee

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ABSTRACT OF THE THESIS

Speech Production and Perception

of Heritage Speakers of Korean

by

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Master of Arts in Linguistics

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Childhood exposure to heritage language has been found to be beneficial when relearning the language as an adult. However, it is not known whether the exposure to heritage language affects the dominant language of the heritage speaker. This study investigates if there is any influence of heritage language (i.e., Korean) on the dominant language (i.e., English) of second-generation Korean-Americans based on their production data, and if there is, whether the Korean-American English "accent" is perceptible by native speakers of English. Two groups of Korean Americans and two groups of monolingual speakers were recruited: nine Korean Americans who were exposed to Korean in childhood (i.e., childhood speakers), three Korean-English bilinguals, ten monolingual English controls and six monolingual Korean controls. The results show that English and Korean vowels produced by the childhood speakers were different from that of the bilinguals and that of the two monolingual control groups, suggesting that incomplete exposure to heritage language in childhood affects one's dominant language. However, the analysis of voice quality measures did not suggest any systematic pattern among the speaker groups. For the perception study, fifty-eight listeners were recruited and were asked to judge the speakers' ethnicity after listening to ten English words produced by either Korean Americans or monolingual English controls. The results revealed that listeners were not able to reliably judge the childhood speakers as Asian Americans, indicating that the acoustic differences are subtle. However, the bilingual speakers were consistently rated as Asian Americans, suggesting that bilingual speech might be what native speakers perceive as "Korean-American English."

The thesis of Eun Hwa Lee is approved.

Megha Sundara

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1. Introduction

Early bilingual populations, especially heritage language speakers, have been getting attention in bilingual research. Benmamoun, Montrul, and Polinsky (2010) define a heritage language speaker as “a child who was born outside the parents’ home country or left the home country before the age of eight.” Heritage language speakers are initially exposed to the language of their parent(s) but their acquisition of this language remains incomplete due to the transition to a dominant language (Benmamoun et al., 2010). Heritage language speakers occupy a unique middle ground in bilingual research in that they exhibit interesting characteristics in language acquisition, re-acquisition of heritage language, and in speech production and perception differences in L1 and L2.

Recent research shows that early childhood exposure confers a benefit in learning a language as an adult, since heritage learners who are in the process of relearning their first language exhibit more native-like speech production and speech perception (e.g., Au et al. 2002; Oh et al., 2003; Knightly et al., 2003; Au et al, 2008). Oh et al. (2003) found that heritage learners who spoke Korean as children demonstrated better speech production and perception skills compared to novice learners. Even heritage learners who were merely exposed to Korean demonstrated better speech perception skills. Similarly, in studies with heritage language speakers of Spanish, Au et al. (2002, 2008) found that adult heritage learners demonstrated more native-like accents as well as better morphosyntactic skills compared to novice learners. These results illustrate that early exposure to a heritage language provides advantages in learning the language again as an adult even when exposure to a heritage language is discontinued.

It is not clear how early exposure to a heritage language affects one's dominant language. However, research in bilinguals can give some guidance. It is well known that bilingual individuals do not behave as monolinguals in speech production (e.g., Caramazza et al. 1973; Khattab, 2000; Guion, 2003; Sundara et al. 2006; Mora and Nadeu, 2012, etc.). Not only does a bilingual's L1 influence their L2 (Piske et al., 2001; Flege et al., 2006), a bilingual's L2 can also change their L1 production (Guion, 2003; Mora and Nadeu, 2012). Currently, there are two influential approaches in L2 speech perception. The first one is the Speech Learning Model (SLM; Flege, 1995). According to the SLM, L1 and L2 phonetic categories exist in a single phonological space. Thus, it is predicted that L2 learners establish new categories for L2 sounds if they perceive phonetic differences between L1 and L2 sounds. If L2 learners do not perceive the differences, L1 and L2 sounds merge into a single category. The second one is the Perceptual Assimilation Model (PAM; Best, 1995), and more recently PAM-L2 (Best and Tyler, 2007) which itself is an extension of PAM. PAM posits that naïve listeners assimilate a non-native sound to one of their L1 categories based on the degree of perceptual distance between the native and non-native sounds. PAM-L2 postulates that L2 learners' perception of target sound changes over time (i.e., "re-phonologize") based on their L2 experience and development. According to PAM-L2, after learners assimilate an L2 sound to one of their L1 categories, the new combined L1/L2 category could be established based on the learners' experience with L2. Thus, PAM-L2 makes a prediction similar to the SLM in that bilinguals' speech sound categories are different from that of monolinguals. According to these two models, L1 and L2 phonetic categories of bilinguals may be different from that of monolinguals, even though these differences are not always perceptible to monolingual speakers (e.g., Sundara et al., 2006).

Heritage language speakers are bilinguals in that they were exposed to and spoke a language that is different from their current dominant language even though their competency in L1 is very limited. The difference between bilinguals and heritage language speakers then lies in the amount of language input and use because the key characteristic in the definition of heritage language speaker is incomplete or discontinued input. On one hand, heritage language speakers might behave like bilinguals and demonstrate L1 influence on their dominant L2 even when the L1 input is insufficient. On the other hand, heritage speakers might behave just like monolinguals because their exposure to the heritage language is not substantive enough to affect the production in their dominant language.

The current study examines the speech production of heritage language speakers of Korean who grew up in California, U.S. There has been research on the English spoken by heritage language speakers of other languages such Mexican Heritage English in the Chicago area (Konopka and Pierrehumbert, 2008) and the Chinese Heritage English in New York City (Wong, 2007). These studies revealed that the English of specific heritage language groups demonstrated characteristics that are different from that of mainstream English. Thus, it is expected that the English of heritage speakers of Korean would also demonstrate acoustic differences in speech production from monolingual English speakers.

The current study also examines whether the English produced by heritage language speakers of Korean is perceptible as "Korean-American English" by native speakers of English. Anecdotal reports illustrate that native English speakers are able to distinguish Caucasian Americans' English from Asian Americans'– Korean or Chinese, even when Asian Americans are native speakers of English and do not exhibit a foreign accent. It is possible that what native English speakers perceive are dialectal characteristics of Asian-American English. In one study, Newman and Wu (2011) found that Chinese-Americans and Korean-Americans have a breathier voice and produce longer VOT in voiceless stops. They also found that Asian Americans' English is more syllable-timed. However, as Newman and Wu (2011) point out, it is difficult to define a single dialect of Asian-American English due to diverse Asian influences. One cause of such heterogeneity could be the diversity of heritage languages in the population of Asian Americans. In this study, I examine the acoustic properties of the English variety spoken by adults sharing one heritage language (i.e., Korean) who grew up in California.

2. Research question

This study investigates the influence of Korean as a heritage language in the production of one's dominant language (i.e., English) by second-generation Korean Americans as well as any perceptible differences in their productions. The research questions of the study are as follows:

1) Does incomplete exposure to the heritage language (i.e., Korean) in childhood affect the production in one's dominant language (i.e., English)? I will answer this by determining if there are any acoustic differences in the speech production of Korean Americans and monolingual Caucasian Americans.

2) If there are acoustic differences, are they perceptible to native English speakers? I will answer this by presenting the results of a perception experiment which examined the perceptibility of acoustic differences in the English of heritage language speakers of Korean.

The current study focuses on the analysis of vowel production and voice quality of Korean-Americans. The following sections discuss the vowel systems of Korean and English and also describe these vowels in terms of formant values and voice quality. The predictions of the research questions are presented at the end of Sections 2.1 and 2.2.

2.1 Korean Vowels

Korean has 7 monophthongs /i, e, ɑ, ʌ, o, u, ɨ/, as shown in Table 1. It is the general consensus that the two front vowels /e/ and /ɛ/ have merged into a single category /e/ (Ahn and Iverson, 2007). In this study, the merged mid front vowel will be presented as /e/.

Table 1. Korean vowel system.

	Front	Central	Back
High	i	ɨ	u
Mid	e	ʌ	o
Low			ɑ

Figures 1a and b show the Korean vowel space for male and female speakers respectively (Yang, 1996). The Korean vowels are shown as "K vowel name" to differentiate them with English vowels. Yang (1996) includes separate values of /e/ and /ɛ/ although he acknowledges the merger of the two vowels.

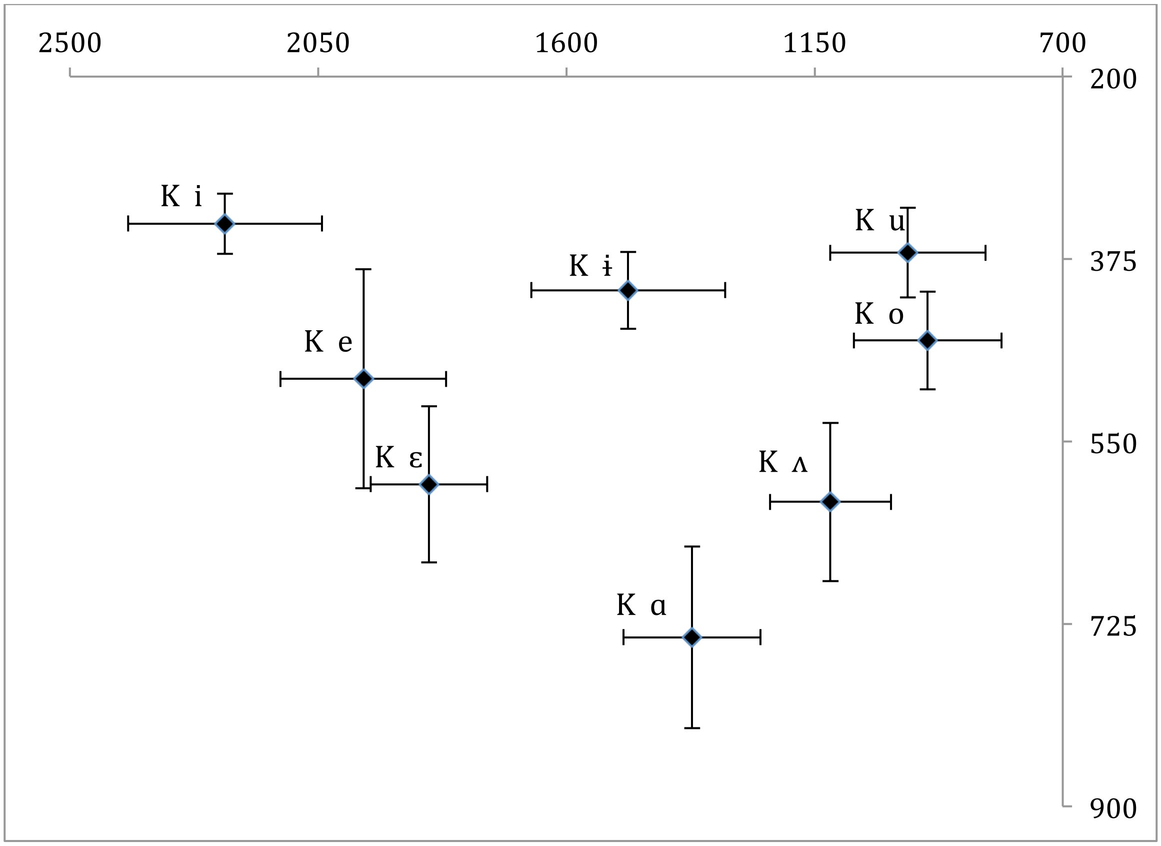

Figure 1a. Korean vowel space of male speakers based on the values from Yang (1996). The vowels are shown as "K vowel name." Each symbol indicates average values of 30 speakers with error bars showing 1 SD.

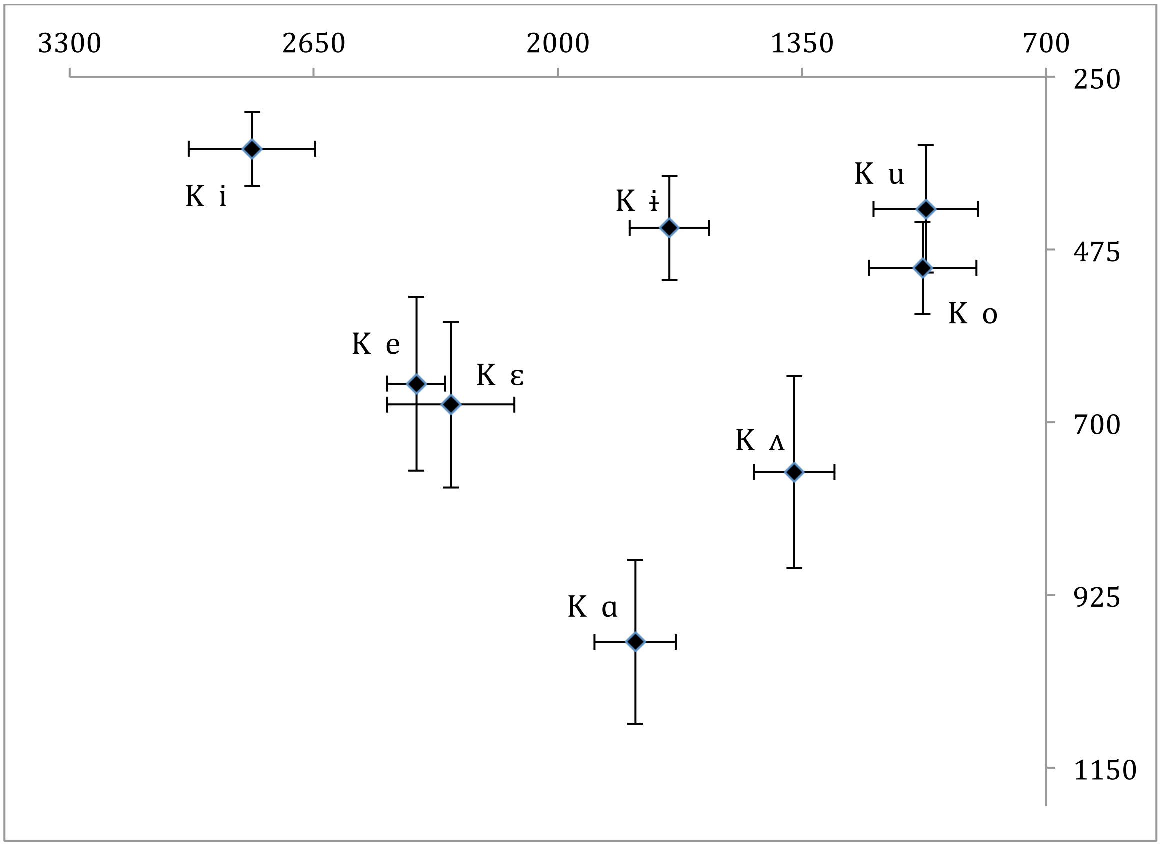

Figure 1b. Korean vowel space of female speakers based on the values from Yang (1996). The vowels are shown as "K vowel name." Each symbol indicates average values of 30 speakers with error bars showing 1 SD.

The vowel inventory of English, as shown in Table 2, is different from that of Korean in that Korean has fewer vowels, does not have off-glide diphthongs such as English /eɪ/ and /oʊ/, and does not have tense/lax distinction such as English /i-ɪ/ and /u-ʊ/ pairs. In addition, a low front vowel, such as English /æ/, does not exist in Korean.

Figures 2a and b show the English vowel space for male and female speakers respectively (Hillenbrand et al., 1995). The data were collected in the Midwest area.

Table 2. English vowel system.

	Front	Central	Back
High- tense	i		u
High-lax	ɪ		ʊ
Mid-tense	eɪ	ə	oʊ
Mid-lax	ɛ	ʌ	ɔ
Low-lax	æ		ɑ

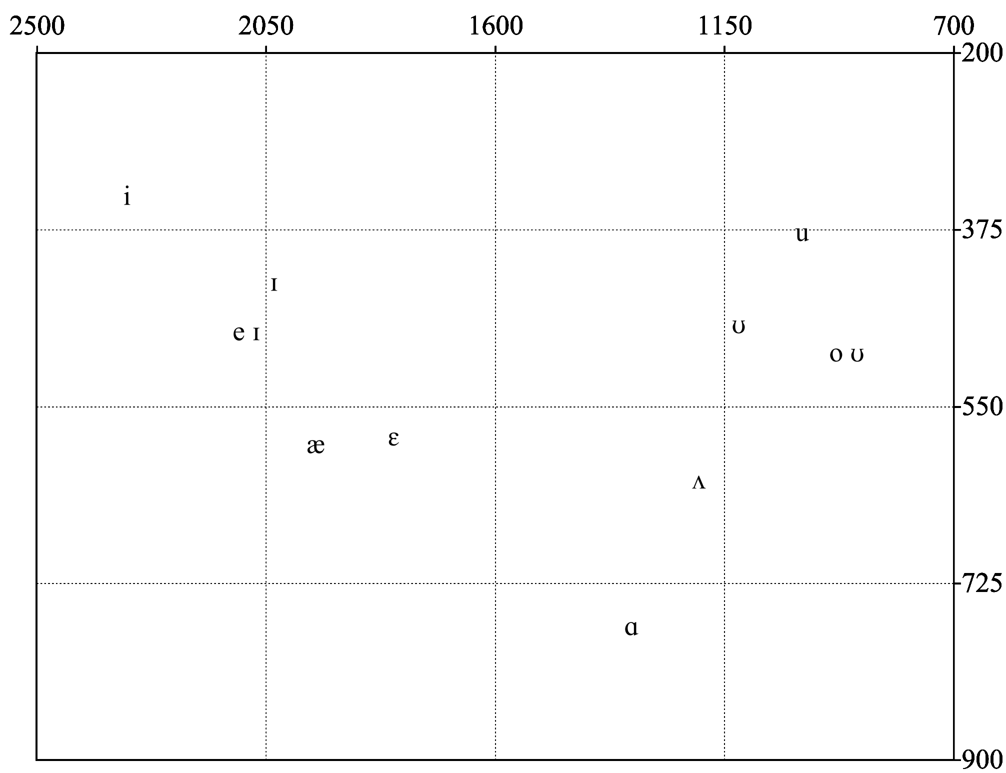

Figure 2a. English vowel space of male speakers based on the values from Hillenbrand et al. (1995). Each symbol indicates average values of 45 speakers.

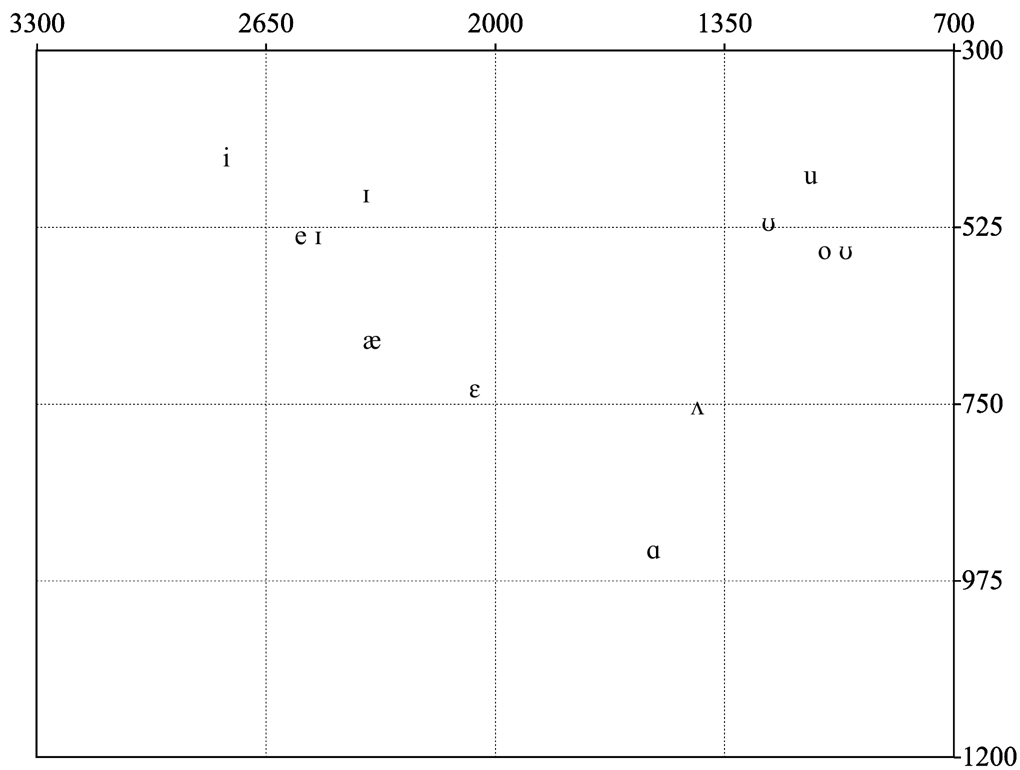

Figure 2b. English vowel space of female speakers based on the values from Hillenbrand et al. (1995). Each symbol indicates average values of 48 speakers.

If heritage language speakers of Korean exhibit influence of Korean on their English productions, it is predicted that their production of English diphthongs /eɪ/ and /oʊ/ would show smaller formant transitions compared to monolingual English speakers due to the lack of off-glide diphthongs in Korean[1]. Also, the production of English /æ/ is predicted to be centralized compared to monolingual speakers if they do not utilize the

[1] I assume that Korean /의/ is an on-glide diphthong /ɯ̥i/.

low front space due to the lack of such a target in Korean. Finally, it is hypothesized that their English /i/ and /u/ may not be as peripheral as monolinguals' due to the lack of a tense/lax distinction in Korean.

2.2 Voice Quality

Korean has a three-way laryngeal distinction in obstruents (i.e., lenis, tense, and aspirated). These are distinguished by VOT, f0, and voice quality. Among these, lenis stops /p, t, k/ and fricative /s/ trigger breathiness in the following vowel (Cho, Jun, & Ladefoged, 2002). Cho et al. (2002) found that vowels following lenis stops and fricative have greater H1-H2 and H1-A2 values than vowels following aspirated and tense stops, although both lenis and aspirated categories triggered breathiness.

H1-H2 is the amplitude difference of the first two harmonics and is known to correlate with glottal open quotient (i.e., the proportion of glottal cycle that the vocal folds are not in contact) (Holmberg et al., 1995). Breathy phonation occurs when the open quotient is high, and it is related to high H1-H2 values (Klatt and Klatt, 1990). H1-A2 is the amplitude difference of the first harmonic and the first formant and it is related to the abruptness of vocal fold closure (Stevens, 1977). Higher H1-A2 values and other spectral tilt values (i.e., H1-A1 and H1-A3) also indicate breathy phonation (Cho et al., 2002; Esposito 2010).

In English, breathiness can occur in the vowels following intervocalic /h/ (Epstein, 1999). However, unlike Korean, English does not have a set of breathiness-triggering consonants. Thus, as reported by Newman and Wu (2011), heritage language speakers of Korean might demonstrate overall breathier voice quality than monolingual English speakers due to a larger number of breathiness-triggering consonants in Korean. However, Newman and Wu did not control the preceding consonant when they measured H1-H2 on the vowels. The current study examines voice quality measures in a more controlled way.

3. Experiment 1

The first experiment was conducted to investigate whether the incomplete childhood Korean language input of Korean-Americans would influence the production of their English vowels. If there were an influence, the English vowel space of Korean-Americans would be different from that of monolingual Caucasian-Americans.

3.1 Method

3.1.1 Stimuli

Ten /hVd/ words and ten /bVd/ words with ten different English vowels (i.e., /ɪ, i, eɪ, ɛ, ɑ, æ, ʌ, ʊ, u, and oʊ/) were selected as stimuli. These target words were taken from Ladefoged (2001): *hid, heed, hayed, head, hod, had, Hudd, hood, who'd, hoed, bid, bead, bayed, bed, bod, bad, bud, book, booed,* and *bode*. The word *book* was included for the vowel /ʊ/ since there is no English word that has a coda /d/ in /bVd/ formant. The words with the initial consonant /h/ were selected to minimize the influence of the preceding consonant to the vowel formants. The stimuli were presented in a carrier phrase "say ___."

Seven Korean CV words with the initial consonant /h/ were selected (i.e., *[ha], [he], [hi], [hʌ], [hɨ], [ho], and [hu]*). CV words were chosen instead of CVC since Korean phonotactics does not allow for /d/ in coda position and the presence of a coda consonant substantially shortens the duration of the vowel in Korean. Thus, the seven nonce words were chosen as target stimuli. The stimuli were presented in a carrier phrase, [igʌn ___] "This is ___." to match the prosodic context of English data.

3.1.2 Participants

Two experimental Korean-American groups and two monolingual control groups were recruited for this study. All participants were recruited from the UCLA campus. The Korean-American participants were divided into two groups (i.e., childhood speakers and bilinguals) depending on their extent of Korean use. The inclusion criteria for the childhood speaker group in this study were adopted from Oh et al. (2003). The childhood speakers (CS) were either born in the U.S. or immigrated to the U.S. before the age of 5. They were primarily exposed to Korean before the age of 6 and were able to speak in sentences and phrases in Korean. Additionally, they experienced a sudden drop in speaking Korean around the age of 5 to 7. After they stopped speaking Korean regularly, their occasional Korean productions were limited to short phrases and single words. In addition, their current use of Korean is limited to a couple of hours per week. These criteria also fit the definition of heritage language speakers as described in Benmamoun et al. (2010) (i.e., incomplete or discontinued input of heritage language). Unlike the childhood speaker group, participants in the bilingual (BL) group did not experience a sudden drop in speaking Korean. They are fluent in English and Korean and speak both languages on a regular basis. The demographic information of the nine childhood speakers (4 female, 5 male) and the three bilinguals (3 female) whose production data were included in the analysis are shown in Table 3.

Table 3. Korean-American participants in Childhood Speaker (SC) and Bilingual (BL) groups.

Childhood Speaker group (CS)					
Subject	Gender	Age	Age of Arrival	Age of Drop in Speaking Korean	Current Korean Use*
CS-MJ	F	21	US born	5	2
CS-KY	M	19	US born	6	0
CS-KS	M	20	US born	7	2
CS-TH	M	21	2	6	1
CS-HP	M	21	0;2	7	<1
CS-SK	F	19	US born	5	<1
CS-DK	M	21	US born	6	<1
CS-EJ	F	18	US born	5	<1
CS-HK	F	21	US born	5	2
Bilingual group (BL)					
Subject	Gender	Age	Age of Arrival	Age of Drop in Speaking Korean	Current Korean Use
BL-JK13	F	21	3	N/A	20
BL-JK14	F	19	US born	N/A	5
BL-JH	F	20	3	N/A	10

* Numbers are speaking hours per week.

Two monolingual control groups were also recruited for this study. Participants in the English control (EC) group (5 female, 5 male, mean age: 22.6) were monolingual English speaking Caucasian-Americans. All the speakers in the English control group grew up in California. Participants in the Korean control (KC) group (3 female, 3 male, mean age: 29) were monolingual Korean speakers whose length of residence in the U.S. was less than 3 months at the time of data collection.

3.1.3 Procedure

All the speakers were recorded in the UCLA Phonetics Lab in a sound-attenuated booth. The participants wore a head-mounted microphone and the recording was done using *PCQuirerX*. Speakers in two Korean-American groups and the Korean control group read English (/hVd/ and /bVd/ words) and Korean (/hV/ syllables) stimuli in carrier phrases twice each. Speakers in the English control group read the English stimuli only. The same /hVd/ and /bVd/ stimuli were presented to each speaker and they first read the /hVd/ list twice and read the /bVd/ list twice with a break in between each repetition. Speakers in the two Korean-American groups and the Korean control group also read the Korean /hV/ list twice. Since the same word lists were presented to all the speakers, every speaker read the words in a fixed order (i.e., /hVd/ stimuli order: *hid, heed, hayed, head, had, hod, hawed, hood, hoed, who'd,* and *Hudd*; /bVd/ stilmuli order: *bid, bead, bayed, bed, bad, bod, bawed, book, bode, booed,* and *bud*; /hV/ Korean stimuli order: *ha, hi, ho, he, hu, hʌ,* and *hɨ*).

3.1.4 Labeling

Ten English vowels and seven Korean vowels were segmented and labeled in Praat (Boersma & Weenink, 2012). The entire /hVd/ words were also segmented from one of the two repetitions to be used as stimuli for Experiment 2. The vowel [eɪ] from "say" in the carrier phrase "Say ___." was also segmented for voice quality measurements. Ten productions of [eɪ] from the carrier phrase were segmented from each speaker. The vowel [eɪ] was chosen since it is not in the phrase-final position which tends to be creaky, a confounding factor in measuring voice quality (all other vowels in the target stimuli were in the phrase-final position). In addition, the preceding consonant /s/ in English is less likely to trigger breathy or tense voice quality.

3.1.5 Measurements

The first two formants of the segmented English and Korean vowels were measured using VoiceSauce (Shue, Keating, & Vicenik, 2009). VoiceSauce uses the Snack Sound Toolkit (Sjölander 2004) to measure the frequencies of the first four formants. In VoiceSauce, vowel duration is optionally divided into sub-segments and the mean value of each formant over each sub-segment is calculated. The default number of sub-segments is set at nine. Values of nine sub-segments were chosen in order to use the values from various sub-segments in the analysis of vowels and voice measures. Of the mean values of the nine sub-segments from the segmented vowel, the mean of the fifth sub-segment (i.e., the mid-point of a vowel) was selected for analysis of eight English monophthong vowels and seven Korean vowels. For English diphthongs /eɪ/ and /oʊ/, the means of the second and the seventh sub-segments were selected for analysis. The differences between the seventh and the second sub-segments were obtained to examine the degree of formant transition within the production of the diphthongs.

Errors from VoiceSauce output were manually corrected using the frequency values obtained from the mid-point of the monophthong vowels in Praat. No errors were found for diphthongs.

The following eight voice quality measurements were obtained using VoiceSauce to examine the voice quality: the corrected amplitude difference of H1 and H2 (i.e., H1*-H2*), the corrected amplitude differences between H1 and the first three formants (i.e., H1*-A1*, H1*-A2*, and H1*-A3*), and Harmonic-to-Noise Ratio (HNR) of the frequency ranges 0-500Hz, 0-1500Hz, 0-2500Hz, and 0-3500Hz (i.e., HNR05, HNR15, HNR25, and HNR35). VoiceSauce uses the STRAIGHT algorithm (Kawahara, Masuda-Katsuse, & de Cheveigné, 1999) to track f0 and the Snack Sound Toolkit to measure the amplitude of the formants. Harmonic-to-Noise Ratios are calculated using de Krom's (1993) algorithm. The mean values of the first two sub-segments from the vowel were included in analysis.

3.2 Results

3.2.1 Vowel Formants

3.2.1.1 Male Speakers

Table 4a shows the mean F1 and F2 frequencies and standard deviations of each English vowel from the male childhood speakers and the English controls. The values of the two diphthongs /eɪ/ and /oʊ/ are the frequency differences between the second and the seventh sub-segments of the diphthong. The formant values of the vowel /ʊ/ from the word *book* were excluded from analysis due to the F2 difference caused by the final consonant /k/. The F2 of /ʊ/ was approximately 300Hz higher across speakers when preceded by /k/ compared to the F2 of /ʊ/ preceding /d/. Data for the vowel /ɔ/ were collected but excluded from analysis since all the participants are from California and did not have /ɔ/ (Ladefoged, 2001). For comparison, the average formant values of the English vowels from Hillenbrand et al. (1995) are shown in Table 4b. The differences seem to be due to dialectal variation as Hillenbrand et al.'s data were collected in the Midwest area. The major difference was that the vowel space from Hillenbrand et al.'s data has one low vowel /ɑ/ whereas the vowel space of the English controls in this study has two low vowels (i.e., /ɑ/ and /æ/).

Table 4a. Mean English vowel formant frequencies in Hz (and SD) produced by childhood speakers (CS) and English controls (EC). /eɪ/ and/oʊ/ values are the frequency difference between the second and the seventh sub-segment of the diphthong.

Vowels	F1 CS	F2 CS	F1 EC	F2 EC
/ɑ/	650 (45)	1125 (101)	646 (66)	1080 (85)
/æ/	692 (36)	1676 (59)	711 (59)	1555 (111)
/i/	278 (24)	2225 (130)	273 (26)	2175 (179)
/ɪ/	423 (20)	1896 (63)	445 (37)	1790 (95)
/ɛ/	557 (39)	1767 (77)	569 (42)	1666 (85)
/ʊ/	454 (22)	1497 (107)	433 (37)	1374 (78)
/u/	320 (22)	1211 (86)	331 (36)	1211 (198)
/ʌ/	569 (29)	1359 (99)	565 (29)	1342 (78)
/eɪ/	74 (13)	126 (52)	100 (20)	160 (73)
/oʊ/	92 (22)	90 (104)	100 (30)	85 (55)

Table 4b. Average values of F1 and F2 in Hz produced by 45 male speakers and 48 female speakers in Hillenbrand et al. (1995).

Vowels	F1 (male)	F2 (male)	F1 (female)	F2 (female)
/ɑ/	768	1333	936	1551
/æ/	588	1952	669	2349
/i/	342	2322	437	2761
/ɪ/	427	2034	483	2365
/ɛ/	580	1799	731	2058
/ʊ/	469	1122	519	1225
/u/	378	997	459	1105
/ʌ/	623	1200	753	1426
/eɪ/	476	2089	536	2530
/oʊ/	497	910	555	1035

Independent sample t-tests were conducted to compare the F1 and F2 values of each vowel produced by the childhood speakers and the English controls. The results revealed a significant group difference in F1 frequency difference of /eɪ/ ($t(38)=4.81$, $p=0.00002$), and F2 of /æ/ ($t(38)=4.28$, $p=0.00012$), /ɪ/ ($t(38)=4.13$, $p=0.00019$), and /ɛ/ ($t(38)=3.92$, p=0.00035) following the Bonferroni adjusted alpha level of 0.005 (i.e., 0.05/10).

Figure 3 shows the vowel space of the childhood speakers and the English controls, with F1 values (in Hz) shown on the Y-axis and F2 values on the X-axis.

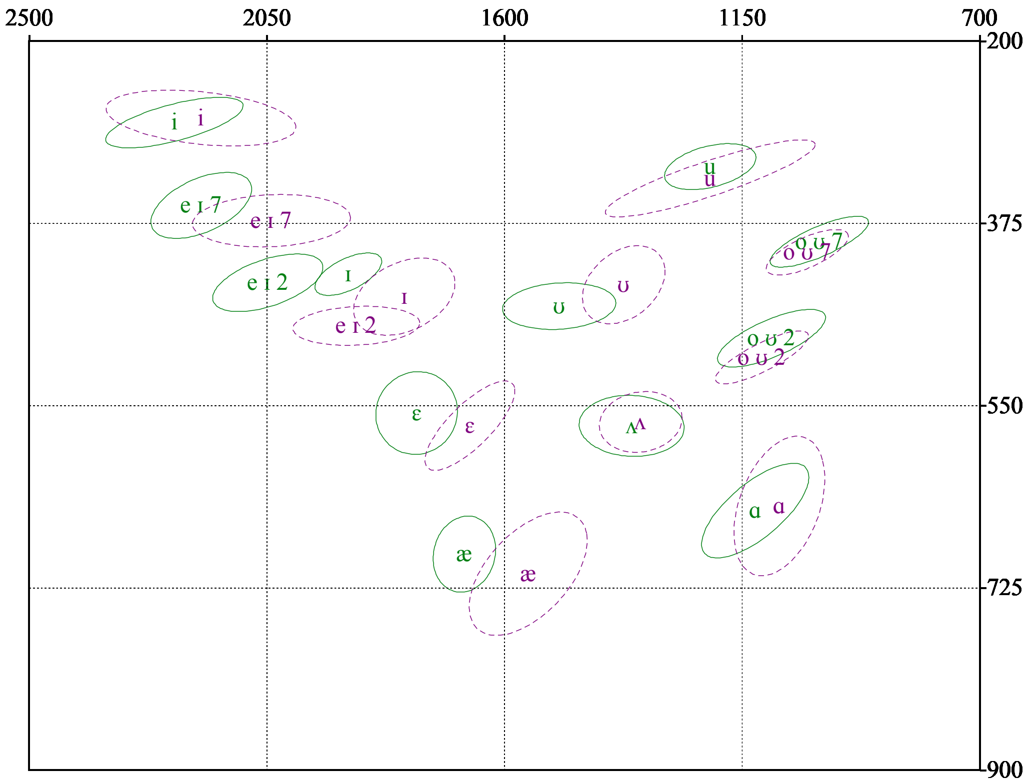

Figure 3. English vowel space of male childhood speakers (in green with solid line) and English controls (in purple with dashed line). The center of each ellipse (shown by the name of the vowel) indicates the average F1 and F2 values. The area each ellipse includes is 1 standard deviation of the formant values. Diphthongs are represented with two different values to illustrate the transitional trajectory. /eɪ2/ and /oʊ2/ are the average formant values from the second sub-segments of the diphthong and /eɪ7/ and /oʊ7/ are the average formant values from the seventh sub-segments.

The subjects in the childhood speaker group demonstrated less F1 transition in the production of /eɪ/ than that of English controls. Additionally, there were significant group differences in the F2 values of /ɪ, ɛ, æ/. The vowel plot shows that all three vowels were fronted in the production of the childhood speakers compared to the English controls.

The differences found in the production of English vowels were examined in comparison of Korean vowels. Table 5a shows Korean vowel formants produced by the childhood speakers and the Korean controls. Data from one male speaker in the Korean control group were excluded due to the formant differences caused by the rising pitch on the target stimuli. For comparison, the average formant values of the Korean vowels from Yang (1996) are shown in Table 5b. In general, the formant values of Korean control were in line with Yang's (1996) data.

Table 5a. Mean Korean vowel formant frequencies in Hz (and SD) produced by male childhood speakers (CS) and Korean controls (KC).

Vowels	F1 CS	F2 CS	F1 KC	F2 KC
/i/	303 (26)	2263 (135)	307 (15)	2134 (119)
/e/	553 (40)	1825 (85)	611 (94)	2031 (189)
/ɑ/	755 (42)	1280 (106)	793 (69)	1261 (148)
/ʌ/	585 (42)	1002 (105)	604 (16)	907 (16)
/o/	444 (29)	797 (63)	389 (13)	740 (16)
/u/	325 (26)	867 (102)	326 (28)	773 (60)
/ɨ/	423 (62)	1334 (84)	360 (24)	1380 (157)

Table 5b. Average values of F1 and F2 in Hz (and SD) produced by 30 male speakers and 30 female speakers in Yang (1996).

Vowels	F1 (male)	F2 (male)	F1 (female)	F2 (female)
/i/	341 (29)	2219 (176)	344 (48)	2814 (168)
/e/	490 (105)	1968 (150)	650 (113)	2377 (77)
/ɛ/	591 (75)	1849 (106)	677 (108)	2285 (169)
/ɑ/	738 (87)	1372 (124)	986 (107)	1794 (108)
/ʌ/	608 (76)	1121 (110)	765 (125)	1371 (108)
/o/	453 (47)	945 (134)	499 (60)	1029 (143)
/u/	369 (43)	981 (141)	422 (83)	1021 (139)
/ɨ/	405 (37)	1488 (176)	447 (68)	1703 (106)

Independent sample t-tests were conducted to compare the F1 and F2 values of each Korean vowel produced by the childhood speakers and the Korean controls. The results revealed significant group difference of F1 of /o/ ($t(12)=3.59$, $p=0.004$) following the Bonferroni adjusted alpha level of 0.007 (i.e., 0.05/7). Figure 4 shows Korean vowel space of the childhood speakers (in green with solid line) and the Korean controls (in red with dashed line).

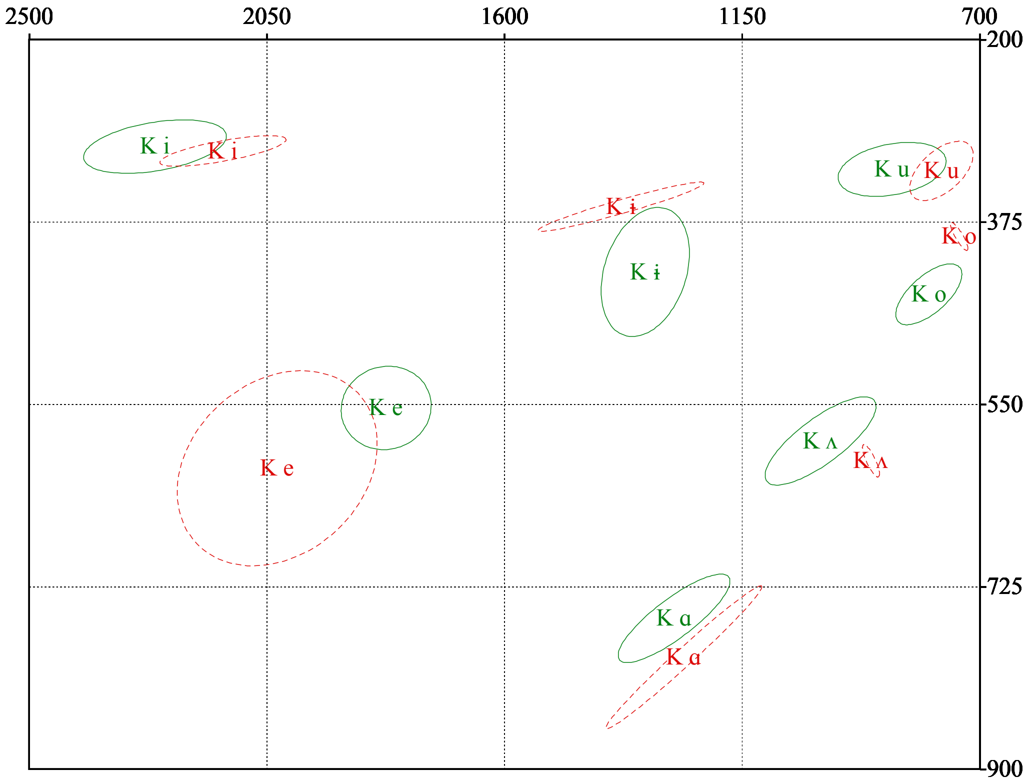

Figure 4. Korean vowel space of male childhood speakers (in green with solid line) and Korean controls (in red with dashed line).

Figure 4 indicates that Korean /o/ produced by the childhood speakers was significantly lower than that of the Korean controls. Figure 5 shows English (in green with solid line) and Korean (in red with dashed line) vowels produced by the male childhood speaker group in the same vowel space.

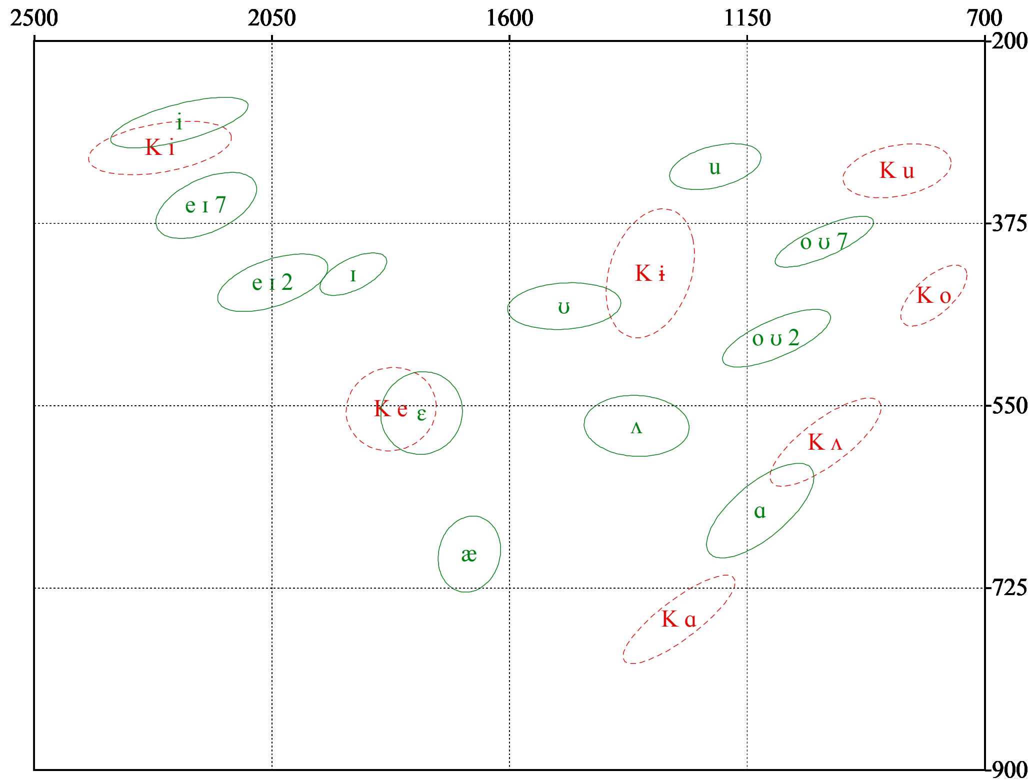

Figure 5. English (in green with solid line) and Korean (in red with dashed line) vowels produced by male childhood speaker group.

According to Figure 5, it seems that the male childhood speakers have an overlapping /i/ category of English and Korean. Paired sample t-tests were conducted to examine the formant differences of English /i/ and Korean /i/. Due to the difference in the number of English and Korean tokens, paired t-tests were conducted using English /hVd/ tokens and Korean /hV/ tokens (i.e., vowels from English /bVd/ tokens were not included in the tests). The t-test results revealed no significant difference either in F1

(($t(9)=1.99$, $p=0.078$) or in F2 (($t(9)=1.53$, $p=0.16$) of English /i/ and Korean /i/. The formant differences of Korean /e/ and English /ɛ/ were also examined. Paired sample t-tests revealed significant difference in F2 (($t(9)=3.04$, $p=0.014$) but no difference in F1 (($t(9)=0.72$, $p=0.487$) of English /ɛ/ and Korean /e/.

To summarize, the male childhood speakers' English vowel production was different from that of the English controls in that their /æ, ɪ, ɛ/ were more front compared to that of the English controls. Their production of /eɪ/ showed less F1 transition, indicating that it was monophthong-like. Comparison between the Korean production of the male childhood speakers and the Korean controls revealed that the male childhood speakers' production of Korean /o/ was significantly lower compared to that of the Korean controls. It was also found that the male childhood speakers' production of Korean /i/ and English /i/ was not significantly different. Their production of Korean /e/ and English /ɛ/ revealed that the F1 of the two vowels was not significantly different. Their F2, on the other hand, was significantly different.

3.2.1.2 Female Speakers

Table 6 shows the mean formant frequencies produced by three female groups: the childhood speakers, bilinguals, and English controls. There were differences in formant values between the English controls and the data from Hillenbrand et al. (1995) in Table 4b likely due to dialectal variation. As it was the case for the data from the male speakers, the main difference in vowel space between Hillenbrand et al.'s data and the

English controls tested here was that the former has one low vowel (i.e., /ɑ/) whereas the latter has two low vowels (i.e., /ɑ/ and /æ/).

Table 6. Mean English vowel formant frequencies in Hz (and SD) produced by childhood speaker (CS), bilingual (BL), and English control (EC) groups. /eɪ/ and/oʊ/ values are the frequency difference between the second and the seventh sub-segments of the diphthong.

Vowel	F1 CS	F2 CS	F1 BL	F2 BL	F1 EC	F2 EC
/ɑ/	828 (45)	1230 (105)	823 (50)	1194 (131)	909 (81)	1323 (114)
/æ/	939 (57)	1798 (140)	928 (48)	1718 (65)	1042 (75)	1833 (80)
/i/	359 (38)	2898 (176)	342 (26)	2795 (84)	356 (19)	3032 (168)
/ɪ/	508 (59)	2308 (135)	525 (69)	2217 (70)	537 (96)	2368 (143)
/ɛ/	720 (70)	2099 (75)	719 (50)	1961 (82)	783 (89)	2106 (116)
/ʊ/	554 (88)	1743 (177)	537 (97)	1613 (129)	582 (33)	1798 (199)
/u/	389 (45)	1469 (177)	343 (26)	1313 (311)	368 (21)	1468 (195)
/ʌ/	735 (56)	1602 (122)	710 (32)	1513 (133)	744 (67)	1776 (174)
/eɪ/	142 (45)	216 (72)	92 (85)	186 (59)	120 (78)	183 (110)
/oʊ/	135 (26)	141 (90)	109 (70)	128 (153)	178 (64)	201 (76)

A one-way between subjects ANOVA was conducted to examine the group effect. Tukey's post-hoc test was also conducted to investigate which groups are significantly different. The ANOVA results of F1 and F2 of each vowel as well as the results from Tuckey's post-hoc test are shown in Table 7.

Table 7. ANOVA and Tukey's post-hoc test results of three female groups on English vowels (CS: childhood speakers, BL: bilinguals, EC: English Controls).

Vowel	F1	F2
/ɑ/	F=9.77 p<0.01** CS-BL, EC-BL**, EC-CS**	F=5.41 p<0.01** CS-BL, EC-BL*, EC-CS
/ɪ/	F=0.6 p<0.55 CS-BL, EC-BL, EC-CS	F=5.32 p<0.01** CS-BL, EC-BL**, EC-CS
/i/	F=1.35 p=0.27 CS-BL, EC-BL, EC-CS	F=9.21 p<0.01** CS-BL, EC-BL**, EC-CS*
/æ/	F=16.49 p<0.01** CS-BL, EC-BL**, EC-CS**	F=4.82 p<0.05* CS-BL, EC-BL**, EC-CS
/ɛ/	F=4.14 p<0.05* CS-BL, EC-BL, EC-CS*	F=9.63 p<0.01** CS-BL**, EC-BL**, EC-CS
/ʊ/	F=0.79 p=0.47 CS-BL, EC-BL, EC-CS	F=2.05 p=0.15 CS-BL, EC-BL, EC-CS
/u/	F=6.77 p<0.01** CS-BL**, EC-BL, EC-CS	F=2.17 p=0.13 CS-BL, EC-BL, EC-CS
/ʌ/	F=1.36 p=0.27 CS-BL, EC-BL, EC-CS	F=13.1 p<0.01** CS-BL, EC-BL**, EC-CS**
/eɪ/	F=1.71 p=0.19 CS-BL, EC-BL, EC-CS	F=0.67 p=0.52 CS-BL, EC-BL, EC-CS
/oʊ/	F=6.13 p<0.01** CS-BL, EC-BL**, EC-CS	F=2.33 p=0.11 CS-BL, EC-BL, EC-CS

Note: Degree of freedom for the F in the ANOVA test is 2, 45 except the vowel /ɪ/ (i.e., $F(2, 21)$). *p<0.05, **p<0.01.

As shown in Table 7, there were significant differences in the formant frequency of F1 of /ɑ, æ, ɛ/ and F2 of /i, ʌ/ between the English controls and the childhood speakers. Significant differences were found in the F1 of /ɑ, æ, oʊ/ and F2 of /ɑ, æ, ɛ, ɪ, i, ʌ/ between the English controls and the bilinguals. F1 of /u/ and F2 of /ɛ/ were significantly different between the childhood speakers and the bilinguals. Figure 6a shows the vowel space of the childhood speakers (in green with solid line) and the English controls (in purple with dashed line) and Figure 6b shows the vowel space of the bilinguals (in blue with solid line) and the English controls (in purple with dashed line).

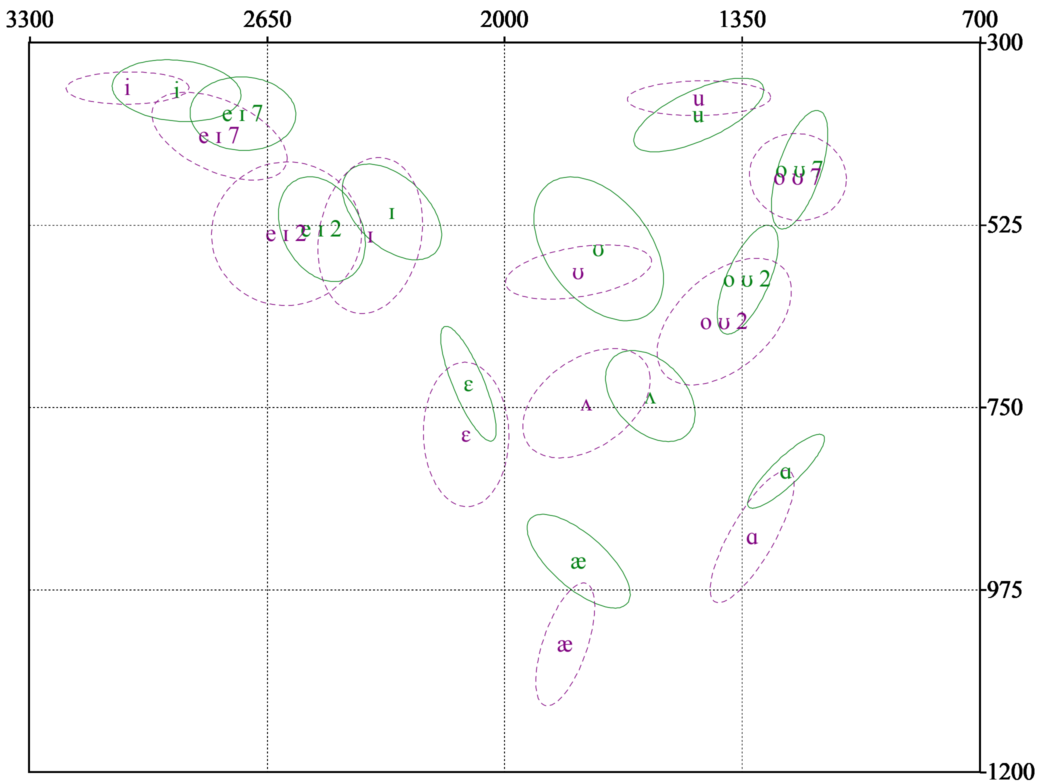

Figure 6a. English vowel space of female childhood speakers (in green with solid line) and English controls (in purple with dashed line). The center of each ellipse (shown by the name of the vowel) indicates the average F1 and F2 values. The area each ellipse includes is 1 SD of the formant values. Diphthongs are represented with two different values to illustrate the transitional trajectory. /ei2/ and /ou2/ are the average formant values of the second sub-segments and /ei7/ and /ou7/ are the average formant values of the seventh sub-segments.

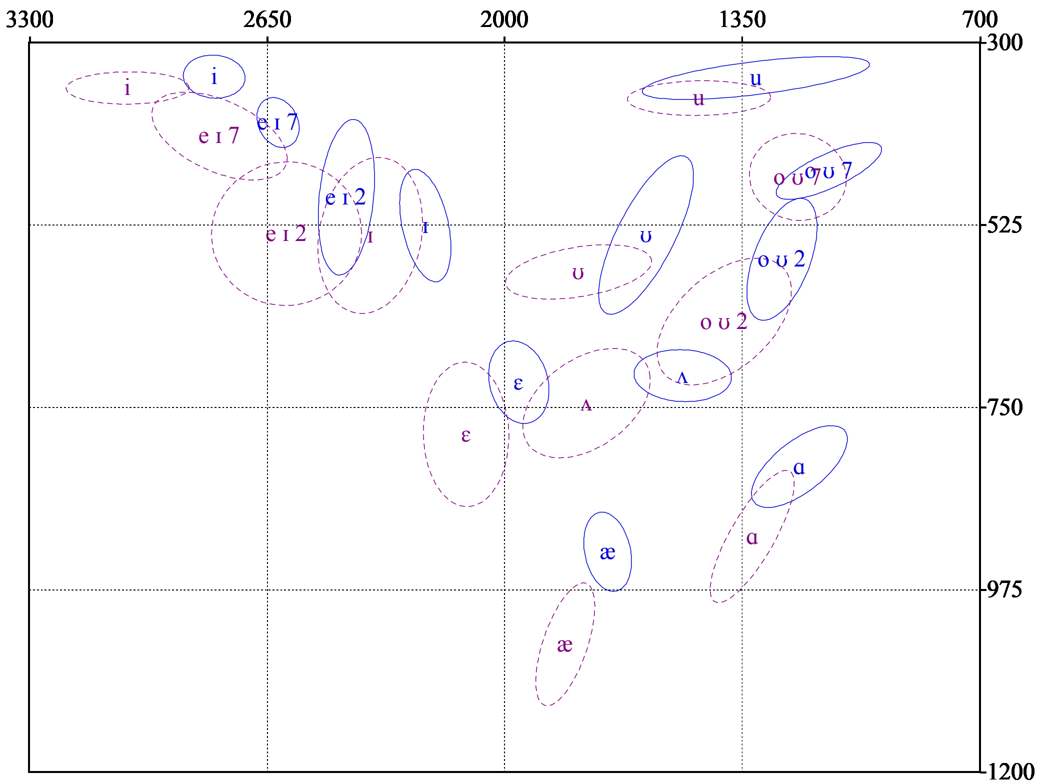

Figure 6b. English vowel space of bilingual speakers (in blue with solid line) and English controls (in purple with dashed line). The center of each ellipse (shown by the name of the vowel) indicates the average F1 and F2 values.

Figure 6a illustrates that the productions of /ɑ, æ, ɛ/ by the childhood speakers are higher than that of the English controls as shown by the lower F1 values. Their productions of /i, ʌ/ were also further back compared to that of the English controls.

Figure 6b reveals that the productions of the bilinguals were significantly different from that of the English controls for a number of vowels. Their /ɑ, æ/ were higher and their /oʊ/ showed less F1 transition compared to that of the English controls. Further, the English vowels produced by the bilingual group were raised and further back. The bilinguals' /ɪ, i, ɛ, ɑ, æ, ʌ/ were more back compared to the English controls'. In particular, less fronted /i/ and less fronted and raised /æ/ indicate that speakers in the bilingual group did not utilize the peripheral space. Compared to the childhood speakers, speakers in the bilingual group produced higher /u/ and less fronted /ɛ/.

The differences found in the production of English vowels were examined in comparison to Korean vowels. Table 8 shows Korean vowel formants produced by three female groups: the childhood speakers, bilinguals and Korean controls. Data from one female speaker in the Korean control group were excluded due to the formant differences caused by the rising pitch on the target stimuli. As it was the case for the male speakers, the formant values of the Korean controls were in line with Yang's (1996) data in Table 5b.

Table 8. Mean Korean vowel formant frequencies in Hz (and SD) produced by female childhood speaker (CS), bilingual (BL), and Korean control (KC) groups.

Vowels	F1 CS	F2 CS	F1 BL	F2 BL	F1 KC	F2 KC
/i/	348 (31)	2894 (195)	374 (22)	2796 (73)	377 (19)	2995 (66)
/e/	661 (19)	2172 (173)	658 (53)	2151 (74)	624 (58)	2485 (145)
/ɑ/	924 (157)	1517 (104)	891 (45)	1427 (69)	1053 (104)	1591 (156)
/ʌ/	741 (31)	1128 (54)	676 (41)	1036 (70)	748 (21)	1056 (56)
/o/	510 (58)	842 (76)	470 (75)	779 (65)	387 (17)	755 (57)
/u/	389 (69)	966 (84)	381 (27)	955 (148)	399 (14)	939 (63)
/ɨ/	507 (116)	1518 (91)	460 (84)	1491 (143)	418 (48)	1622 (68)

Table 9. ANOVA and Tukey's post-hoc test results of three female groups on Korean vowels (CS: childhood speakers, BL: bilinguals, EC: English Controls).

Vowel	F1	F2
/i/	*F*=2.34 *p*=0.13 CS-BL, KC-BL, KC-CS	*F*=2.36 *p*=0.13 CS-BL, KC-BL, KC-CS
/e/	*F*=1.11 *p*=0.36 CS-BL, KC-BL, KC-CS	*F*=8.10 *p*< 0.01** CS-BL, KC-BL**, KC-CS**
/ɑ/	*F*=2.37 *p*=0.13 CS-BL, KC-BL, KC-CS	*F*=2.91 *p*=0.085 CS-BL, KC-BL, KC-CS
/ʌ/	*F*=8.3 *p*< 0.01** CS-BL**, KC-BL*, KC-CS	*F*=4.46 *p*=0.03* CS-BL*, KC-BL, KC-CS
/o/	*F*=5.71 *p*=0.014* CS-BL, KC-BL, KC-CS*	*F*=2.63 *p*=0.11 CS-BL, KC-BL, KC-CS
/u/	*F*=0.15 *p*=0.86 CS-BL, KC-BL, KC-CS	*F*=0.09 *p*=0.92 CS-BL, KC-BL, KC-CS
/ɨ/	*F*=1.22 *p*=0.32 CS-BL, KC-BL, KC-CS	*F*=1.93 *p*=0.18 CS-BL, KC-BL, KC-CS

Note: Degree of freedom for the *F* in the ANOVA test is 2, 15. *p<0.05, **p<0.01.

As shown in Table 9, there were significant differences in the formant frequencies of F1 of /o/ and F2 of /e/ between the Korean controls and the childhood speakers. The bilinguals and the Korean controls demonstrated differences in F1 of /ʌ/ and F2 of /e/. Figure 7a shows Korean vowel space of the childhood speakers (in green with solid line) and the Korean controls (in red with dashed line) in the same vowel space. Figure 7b shows Korean vowels produced by the bilinguals (in blue with solid line) and the Korean control (in red with dashed line).

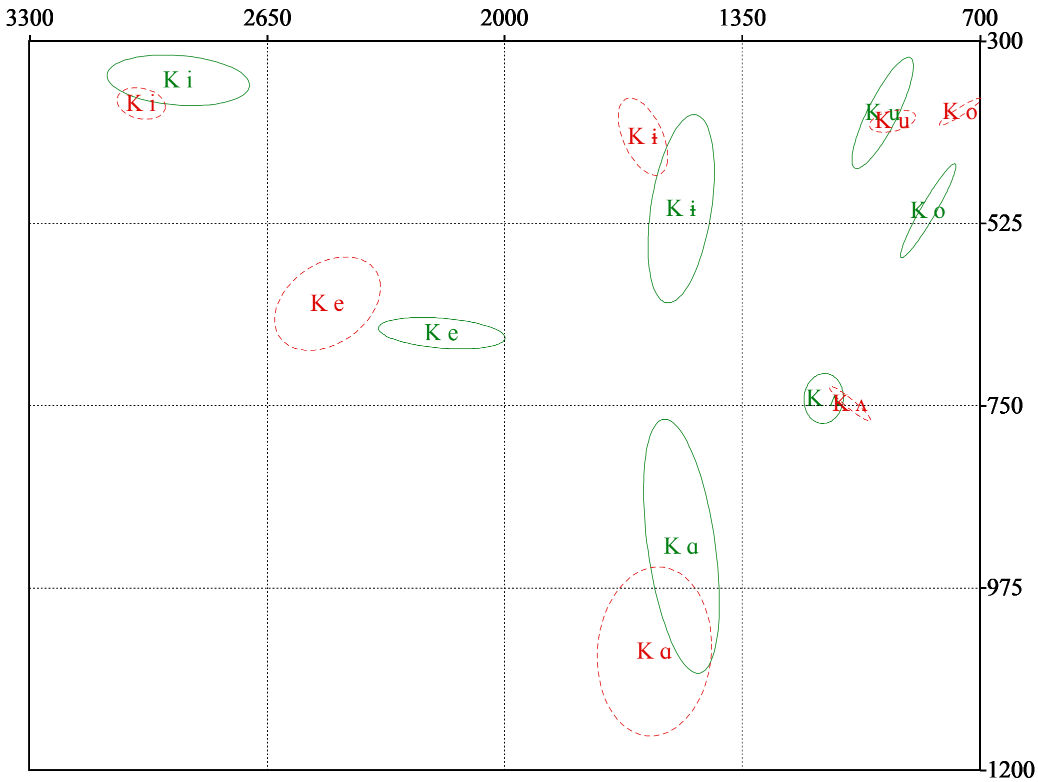

Figure 7a. Korean vowel space of female childhood speakers (in green with solid line) and Korean controls (in red with dashed line).

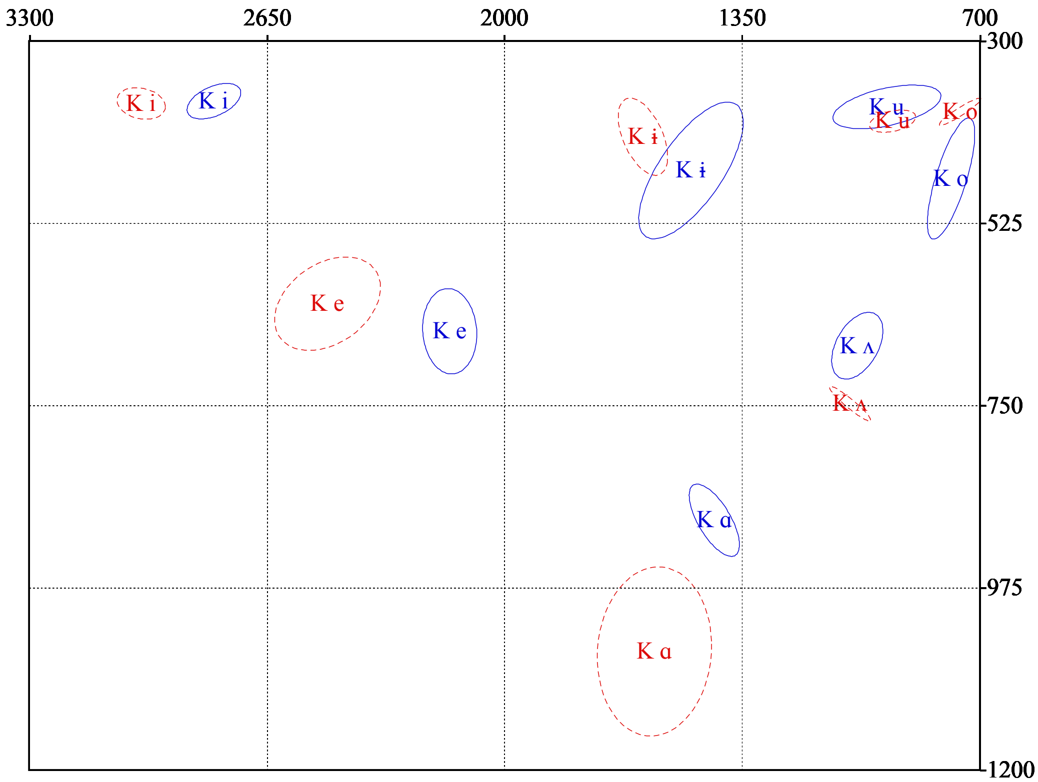

Figure 7b. Korean vowel space of female bilinguals (in blue with solid line) and Korean controls (in red with dashed line).

Figures 7a and b indicate that Korean /e/ was further back in both the childhood speakers and the bilinguals compared to the Korean controls. The childhood speakers additionally produced lower /o/ whereas the bilinguals produced a higher Korean /ʌ/ than the Korean controls.

Figures 8a and b show English and Korean vowels produced by the female childhood speakers and the bilinguals respectively.

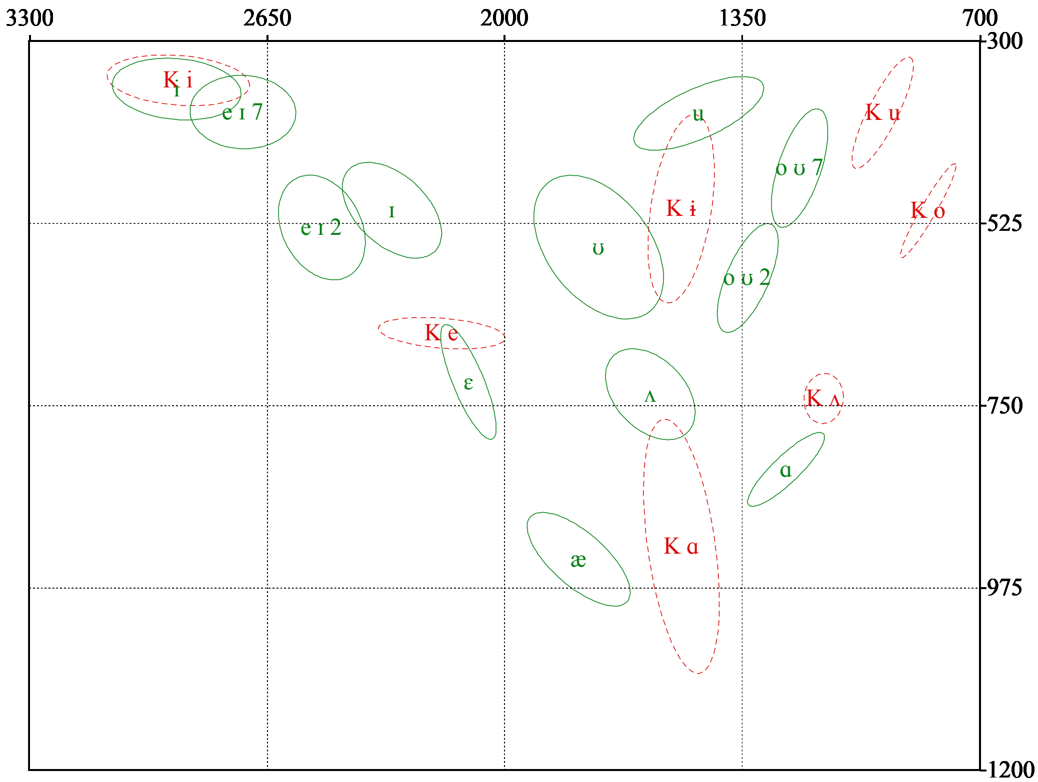

Figure 8a. English (in green with solid line) and Korean (in red with dashed line) vowels produced by female childhood speaker group.

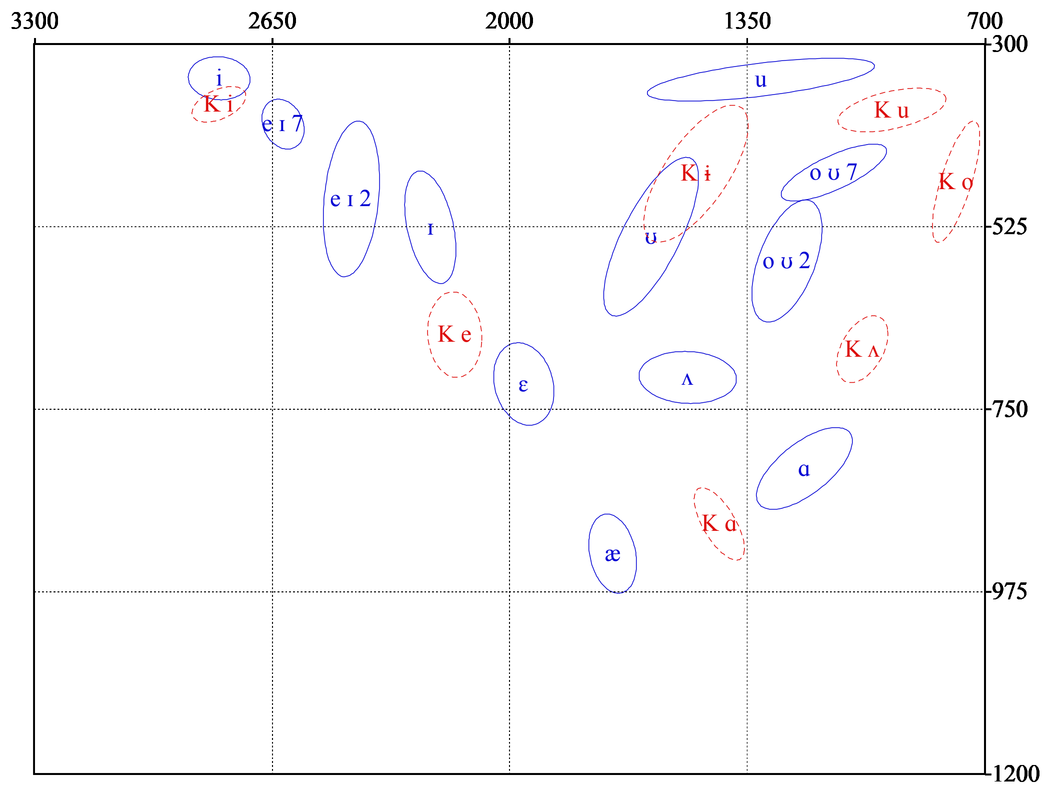

Figure 8b. English (in blue with solid line) and Korean (in red with dashed line) vowels produced by female bilingual group.

Figure 8a illustrates that the female childhood speakers pattern with the male childhood speakers in that both groups have an overlapping category for Korean /i/ and English /i/. Paired sample t-tests revealed no significant different in F1 ($t(7)$=0.009, p=0.993) or F2 ($t(7)$=0.089, p=0.931) of English /i/ and Korean /i/. There was also no significant difference in F1 ($t(7)$=2.19, p=0.065) or F2 ($t(7)$=1.96, p=0.09) of Korean /e/ and English /ɛ/.

Figure 8b shows that the bilingual group does not seem to have any completely overlapping category of Korean and English vowels. Paired sample t-tests revealed no difference in F2 ($t(5)=1.03$, $p=0.348$) but significant difference in F1 ($t(5)=3.6$, $p=0.016$) of English /i/ and Korean /i/. As shown in Figure 8b, paired sample t-tests revealed significant differences in F1 ($t(5)=4.1$, $p=0.009$) and F2 ($t(5)=2.92$, $p=0.032$) of Korean /e/ and English /ɛ/, indicating no overlap of Korean /e/ and English /ɛ/.

To summarize, the female childhood speakers' English vowel production was different from that of the English controls in that their /ɑ, æ, ɛ/ were higher and their /i, ʌ/ were retracted compared to that of the English controls. Comparison between the Korean production of the female childhood speakers and the Korean controls revealed that the female childhood speakers' production of Korean /o/ was lower and their Korean /e/ was retracted compared to that of the Korean controls. It was also found that the female childhood speakers' production of Korean /i/ and English /i/ was not significantly different as well as their production of Korean /e/ and English /ɛ/.

The bilingual speakers' production of English /ɑ, æ/ were higher compared to that of the English controls. They also demonstrated less F1 transition of the diphthong /oʊ/. Their English /ɑ, æ, ɛ, ɪ, i, ʌ/ were retracted compared to that of the English controls. As it was the case for the female childhood speakers, the bilinguals' Korean /e/ was retracted compared to the Korean controls. Their Korean /ʌ/ was higher than that of the Korean controls. However, unlike the two childhood speaker groups, the bilinguals' Korean /e/

and English /ε/ did not overlap. The F2 of their Korean and English /i/ overlapped but their F1 values of the two vowels were significantly different.

3.2.2 Voice Quality

3.2.2.1 Male Speakers

The eight voice quality measurements from three male groups (i.e., childhood speakers, English controls, and Korean controls) were compared using one-way between-subjects ANOVA and Tukey's post-hoc tests as shown in Table 11. See Appendix A for raw values.

Table 11. ANOVA and Tukey's post-hoc test results on 8 voice quality measures from three male speaker groups (CS: childhood speakers, KC: Korean controls, EC: English Controls).

Measurements	ANOVA Results	Tukey's post-hoc test results
H1*-H2*	F=1.45 p=0.24	EC-CS, KC-CS, KC-EC
H1*-A1*	F=6.79 p<0.01**	EC-CS, KC<CS**, KC-EC
H1*-A2*	F=8.24 p<0.01**	EC>CS**, KC-CS, KC-EC
H1*-A3*	F=1.86 p=0.16	EC-CS, KC-CS, KC-EC
HNR05	F=24.47 p<0.01**	EC-CS, KC>CS**, KC>EC**
HNR15	F=17.68 p<0.01**	EC-CS, KC>CS**, KC>EC**
HNR25	F=14 p<0.01**	EC-CS, KC>CS**, KC>EC**
HNR35	F=10 p<0.01**	EC-CS, KC>CS**, KC>EC**

Note: Degree of freedom for the F in the ANOVA is 2, 117. *p<0.05, **p<0.01.

The ANOVA result indicates no effect of group in H1*-H2* unlike the initial hypothesis. The H1*-A1* and the H1*-A2* values show that the childhood speakers have a breathier voice compared to the Korean controls but less breathy compared to the English controls. That is, the English controls have the breathiest voice quality and the Korean controls have the least breathy voice quality. The four HNR measures indicate that the childhood speakers and the English controls have a breathier voice quality compared to the Korean controls as shown by the lower HNR values (Garellek, 2010). In sum, the measurements consistently indicate that Korean controls produced the least breathy voice among the three groups.

3.2.2.2 Female Speakers

The eight voice quality measurements from four female groups (i.e., childhood speakers, bilinguals, English controls, and Korean controls) were compared using one-way between subjects ANOVA and Tukey's post-hoc tests as shown in Table 12. See Appendix B for raw values.

Table 12. ANOVA and Tukey's post-hoc test results on 8 voice quality measures from four female speaker groups (CS: childhood speakers, BL: bilinguals, KC: Korean controls, EC: English Controls).

Measurements	ANOVA Results	Tukey's post-hoc test results
H1*-H2*	F=6.6 $p<0.01$**	CS-BL, EC-BL, KC>BL**, EC-CS, KC>CS**, KC-EC
H1*-A1*	F=8.36 $p<0.01$**	CS-BL, EC-BL, KC-BL, EC>CS**, KC-CS, KC-EC
H1*-A2*	F=54.67 $p<0.01$**	CS<BL**, EC-BL, KC<BL**, EC>CS**, KC>CS**, KC<EC**
H1*-A3*	F=39.58 $p<0.01$**	CS<BL**, EC<BL*, KC-BL, EC>CS**, KC>CS**, KC<EC**
HNR05	F=15.17 $p<0.01$**	CS>BL*, EC<BL*, KC-BL, EC<CS**, KC-CS, KC>EC**
HNR15	F=26.17 $p<0.01$**	CS-BL, EC<BL**, KC-BL, EC<CS**, KC-CS, KC>EC**
HNR25	F=25.62 $p<0.01$**	CS-BL, EC<BL**, KC>BL**, EC<CS**, KC-CS, KC>EC**
HNR35	F=26.01 $p<0.01$**	CS-BL, EC<BL**, KC>BL**, EC<CS**, KC>CS**, KC>EC**

Note: Degree of freedom for the F in the ANOVA test is 3, 136. *$p<0.05$, **$p<0.01$.

The ANOVA results indicate significant group effect in all eight measures. It was predicted that the voice quality of the Korean controls would be the breathiest and the childhood speakers would be breathier than the English controls. The H1*-H2*, H1*-A2*, and H1*-A3* values of the Korean controls were higher than that of the childhood speakers. These results seem to suggest that the Korean controls have a breathier voice quality as predicted. However, higher H1*-H2* and higher spectral tilt values (i.e., H1*-A1*/A2*/A3*) do not always indicate a breathier quality as they can also indicate a less creaky voice (Garellek and White, 2012). Thus, if higher H1*-H2* and higher spectral tilt measures truly indicate breathy quality, it should be confirmed with lower HNR values. The HNR05, HNR15, and HNR25 indicate no group difference between the Korean control and the childhood speakers. HNR35 shows that the childhood speakers were breathier compared to the Korean controls. Thus, the Korean controls do not seem to demonstrate a breathier voice quality. On the other hand, higher spectral tilt values and lower HNR values show that the English controls demonstrated a breathier voice quality compared to the Korean controls and the childhood speakers. In sum, the measurements consistently indicate that the English controls have the breathiest voice quality.

3.3 Discussion

Table 10 is the summary of differences found in vowel production by the three Korean-American groups: male childhood speakers, female childhood speakers, and female bilinguals.

Table 10. Summary of differences in vowels production by three Korean-American groups. Descriptions are relative to the monolingual control groups.

Groups	English	Korean
Male Childhood speakers	- Less F1 transition of /eɪ/ - Fronted /æ, ɪ, ɛ/	- Lower /o/
Female Childhood speakers	- Higher /ɑ, æ, ɛ/ - Retracted /i, ʌ/	- Lower /o/ - Retracted /e/
Female Bilinguals	- Higher /ɑ, æ/ - Less F1 transition of /oʊ/ - Retracted /ɑ, æ, ɛ, ɪ, i, ʌ/	- Higher /ʌ/ - Retracted /e/

The differences that the three Korean-American groups demonstrated in their English production compared to the English controls can be interpreted in terms of Korean influence. The male childhood speaker group demonstrated less F1 transition of /eɪ/ and the female bilingual group produced monophthong-like /oʊ/, possibly due to the lack of off-glide diphthongs in Korean. Likewise, the production of /æ/ by all three Korean-American groups were different from that of the English controls, which seems to have been caused by the lack of a low front vowel target in Korean.

The male and female childhood speakers merged some of their English and Korean vowels into a single category, indicating that the two vowel systems could have interacted with each other. The male childhood speakers demonstrated merger of Korean /i/ and English /i/. They also merged F1 of Korean /e/ and English /ɛ/. The female childhood speakers demonstrated complete merger of Korean /i/ and English /i/, which seems to have been achieved by retracting their English /i/. The merger of Korean /e/ and English /ɛ/ can explain their retracted Korean /e/ and higher English /ɛ/ compared to the English controls. Unlike the two childhood speaker groups, the bilinguals maintained separate categories of Korean /e/ and English /ɛ/. The F2 of their Korean /i/ and English /i/ merged but the F1 values were significantly different.

The three groups demonstrated differences in the way they produced English and Korean vowels compared to the monolingual control groups. The male speakers fronted English vowels while none of the English vowels produced by the two female speaker groups were fronted. Rather, the two female groups raised their English vowels.

Specifically, the higher /æ/ of the female childhood speakers and the higher and retracted /æ/ of the bilinguals indicate that the two female groups did not utilize the low front space. Higher /æ/ and higher /ɑ/ of these two groups made their overall vowel space smaller. The male childhood speakers showed less F1 transition of the front diphthong /eɪ/ whereas the female bilingual speakers showed less F1 transition of the back diphthong /oʊ/. In terms of Korean vowels, the male and female childhood speaker groups patterned together in that both groups lowered Korean /o/ possibly due to English influence. The female childhood speakers and the bilinguals patterned together in that they both retracted Korean /e/.

The analysis of voice quality did not indicate any systematic pattern among the speaker groups. It was hypothesized that the Korean controls would demonstrate breathiest voice quality due to the number of breathiness-triggering consonants in Korean. Following this, it was also hypothesized that the three Korean-American groups would demonstrate breathy voice quality due to Korean influence. The results from the male speaker groups showed that the Korean controls have the least breathy voice, which is against the initial hypothesis. It is possible that the Korean control group demonstrated less breathy quality than the other two groups due to the way they produced the preceding consonant /s/ in *say*. That is, Korean tense consonants tend to trigger lower H1-H2 and H1-A2 (Cho, Jun, & Ladefoged, 2002). In addition, English /s/ in onset position is perceived as Korean tense /s*/ by native speakers of Korean (Cheon and Anderson, 2008). As a result, English /s/ is adapted to Korean tense /s*/ in English loanwords to

Korean (Kang, 2003; Oh, 2012). Therefore, the production of English /s/ by the Korean controls might have been influenced by the Korean tense consonant /s*/. The results from the female speaker groups showed that the English controls have the breathiest voice. It is unclear why the female English controls demonstrated a breathier voice than the other groups.

The between-group differences found in the analysis of vowel production and voice quality suggest that there might be other factors that contribute to the differences observed in Experiment 1. One could assume that if the group differences are due to the influence of their heritage language, the three Korean-American groups should demonstrate a similar pattern. However, differences were observed between the male and female groups as well as the childhood speaker and the bilingual groups. One possible explanation is social identity as second-generation Korean-Americans. The three groups might have produced vowels that are different from that of the English controls to express their group identity. This hypothesis was illustrated in the research of vowel production of gay, lesbian, and bisexual individuals (Pierrehumbert et al., 2004). The results revealed that gay men's vowel production was not shifted toward heterosexual female speakers nor lesbian women's production shifted toward heterosexual male speakers. If so, social identity could be the underlying factor for the different characteristics of the male and the female speakers in current study (i.e., the male childhood speakers' fronted English vowels and the female speakers' retracted English vowels compared to the English controls). In addition, the difference between the childhood speaker and the bilingual groups can also be interpreted in terms of social network. Wong (2007) investigated the vowel production of four Chinese-American females and revealed that their vowel production differed depending on their social ties with the Chinese community. The bilingual speakers in the current study were different from the childhood speakers in terms of the number of hours they speak Korean per week as well as their Korean proficiency. Thus, those differences could have affected the vowel production of the bilingual speakers. Future research should include a detailed questionnaire to examine speakers' social identity and degree of interaction with heritage community.

4. Experiment 2

A perception experiment was conducted to investigate whether the acoustic differences found in Experiment 1 are perceptible to native English listeners. Previous research has revealed that acoustic differences that simultaneous bilinguals exhibit might not always be perceptible to listeners (Sundara et al., 2006). This experiment examines the perceptibility of the heritage language influence in English. The perception experiment specifically targets the differences in vowel production and examines whether an "Asian-American accent" is perceptible by native speakers of English as has been reported so anecdotally.

4.1 Method

4.1.1 Stimuli

Ten English /hVd/ words recorded for Experiment 1 were extracted from the carrier phrase from one of the two repetitions that the speakers produced. The words were concatenated as a single sound file with a 300ms pause inserted in between words. One sound file was generated for each speaker from the English controls, the childhood speakers, and the bilinguals in Experiment 1 (n=22). The average duration of the 22 sound files was 7.51 seconds (range 6.58-9.01 seconds).

4.1.2 Participants

Fifty-eight listeners (39 female and 19 male, age range 17-37, mean age 20.5) were recruited from the psychology subject pool at UCLA and the participants received course credit for their participation. All listeners were self-identified native English speakers.

4.1.3 Procedure

A script for the perception experiment was created using *MATLAB*. The experiment was conducted in a sound-attenuated booth and the listeners wore headphones during the experiment. The instruction was presented on the computer monitor followed by two practice items before the test items were presented. Listeners were instructed to listen to ten English words produced by various speakers and judge whether each speaker was likely to be an Asian American or a Caucasian American. A continuous rating scale was presented on the screen and the listeners were able to drag the bar along the scale to indicate their rating. Figure 9 shows the schematic design of the rating scale. Twenty-two sound files were played in a random order and the listeners were given an option to listen to the stimulus a second time, if they wanted.

	Is the speaker an Asian American?	
Very likely to be an Asian American	<---------------□------------->	Very likely to be a Caucasian American

Figure 9. Continuous rating scale presented to the listeners.

4.1.4 Measurements

The continuous rating scale was designed in the format that the mid-point was set at 50 and the left end of the bar was assigned as 0 and the right end was assigned as 100. For example, if the listeners dragged the bar to the left end point of the scale (i.e., "very likely to be an Asian American"), the collected score was 0. The numbers were not presented on the continuous scale during the experiment. Thus, the listeners did not know what number they assigned to each speaker.

4.2 Results

4.2.1 Male Speakers

Figure 10 shows the average rating each male speaker (five English controls and five childhood speakers) received.

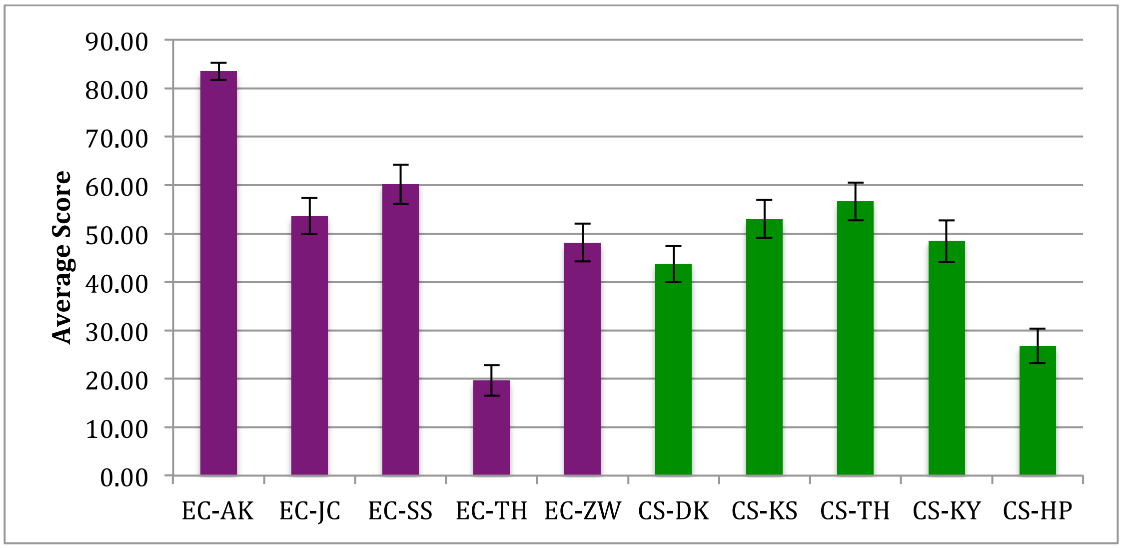

Figure 10. Average rating score of each male speaker with error bars indicating a standard error (EC: English controls, CS: childhood speakers).

Figure 10 indicates that there is more individual variability than group differences. As a group, the average rating score of the English controls was 53.01 and that of the childhood speakers was 45.72. In addition, some speakers received scores that are opposite to their ethnicity. For example, EC-TH was rated more likely to be an Asian-American and EC-ZW was rated slightly likely to be an Asian-American even though they were English controls. Likewise, CS-KS and CS-TH were rated as slightly likely to be a Caucasian American.

To investigate which vowels affected the listeners' rating, pairwise correlations between the rating score and each speaker's F1 and F2 distances from the average formant values of the English controls as well as those between the rating score and each speaker's Euclidian distance from the average values of the English controls were examined. It was assumed that native English speakers have a normative vowel space in their perceptual space so that they can recognize differences when they hear a token that is away from the target in their perceptual space. Tables 13a and 13b show the pairwise correlation results.

Table 13a. The correlation and p values between the F1 and F2 distances from the average values of English controls and the rating score of male speakers. Numbers 2 and 7 on /eɪ/ and /oʊ/ indicate the second and the seventh sub-segments.

Vowel Formants	Pearson's r	p
F1 /ɑ/	-0.01353151	0.9704
F2 /ɑ/	-0.7245769	0.01777*
F1 /ɪ/	-0.740578	0.01429*
F2 /ɪ/	0.008654302	0.9811
F1 /i/	0.1640067	0.6507
F2 /i/	-0.4284103	0.2167
F1 /æ/	0.3537297	0.316
F2 /æ/	0.2134581	0.5538
F1 /ɛ/	-0.1407896	0.6981
F2 /ɛ/	-0.06575769	0.8568
F1 /ʊ/	-0.1964453	0.5865
F2 /ʊ/	0.2333367	0.5165
F1 /u/	0.4800386	0.1603
F2 /u/	0.3953241	0.2582
F1 /ʌ/	0.04583996	0.8999
F2 /ʌ/	-0.1508414	0.6774
F1 /oʊ2/	-0.09657547	0.7907
F2 /oʊ2/	-0.4511152	0.1907
F1 /oʊ7/	0.6013	0.6013
F2 /oʊ7/	0.1364902	0.7069
F1 /eɪ2/	-0.5036407	0.1378
F2 /eɪ2/	-0.06467625	0.8591
F1 /eɪ7/	-0.6428854	0.04497*
F2 /eɪ7/	0.002889891	0.9937

Table 13b. The correlation and p values between the Euclidian distances from the average values of English controls and the rating score of male speakers.

Vowel	Pearson's r	p
/ɑ/	-0.6671074	0.0351*
/ɪ/	-0.1482643	0.6827
/i/	-0.4018201	0.2497
/æ/	0.3224166	0.3636
/ɛ/	-0.1379518	0.7039
/ʊ/	0.2435454	0.4977
/u/	0.4092219	0.2403
/ʌ/	-0.1289226	0.7226
/eɪ2/	-0.1118807	0.7583
/eɪ7/	-0.0687018	0.8504
/oʊ2/	-0.4229596	0.2233
/oʊ7/	0.1472961	0.6847

Table 13a shows that F2 of /ɑ/, F1 of /i/, and F1 of the seventh sub-segment of /eɪ/ are significantly correlated with the rating score. Negative r values indicate that the less the difference from the average values, the higher score the speakers received. These three predictors (i.e., F2 /ɑ/, F1 /i/, and F1 /eɪ7/) were selected as variables predicting the rating scores in a multiple regression model. The two significant predictors were F2 of /ɑ/ (β=-0.177, $p < 0.01$) and F1 of /i/ (β=-0.411, $p < 0.05$).

Table 13b indicates that /ɑ/ is significantly correlated with the rating score. A regression model was investigated using two Euclidian distances (i.e., /ɑ/ and /oʊ2/) as predictors. The two input variables /ɑ/ (β=-0.246, $p < 0.01$) and the second sub-segment of /oʊ/ (β=-0.166, $p < 0.05$) were significant predictors.

Comparison of the above two regression models revealed that the Euclidian distances are a better model to predict the rating score ($p < 0.01$). However, it should be noted that the results from multiple regression models should be interpreted with caution since they were based on 10 observations.

4.2.2 Female Speakers

Figure 11 shows the average rating each female speaker (five English controls, four childhood speakers and three bilinguals) received.

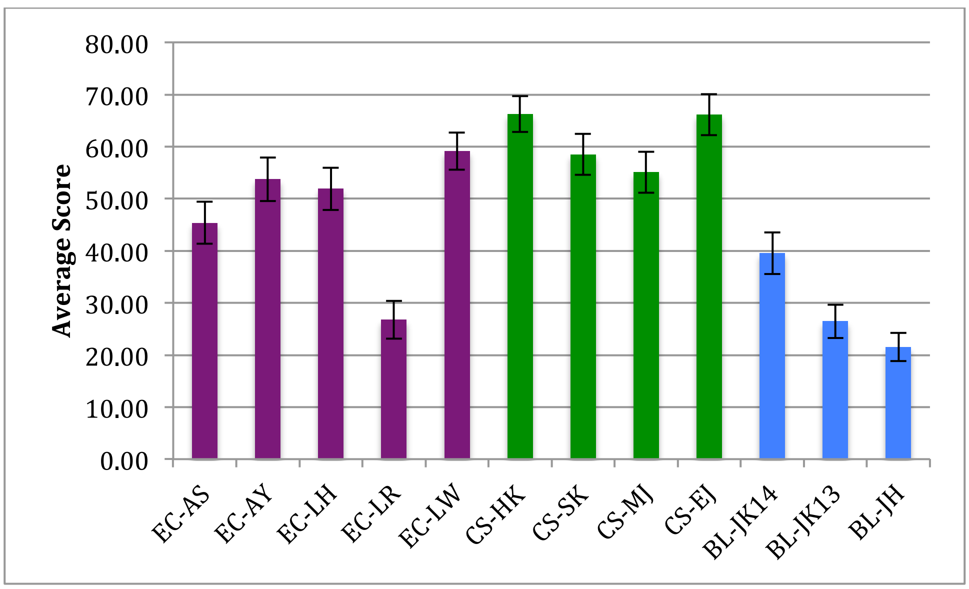

Figure 11. Average rating score of each female speaker with error bars indicating a standard error (EC: English controls, CS: childhood speakers, BL: bilinguals).

As illustrated in the Figure 11, the female speakers demonstrated group differences. The group averages of the English controls, the childhood speakers, and the bilinguals were 47.38, 61.49, and 29.16, respectively. Interestingly, the group average of the English controls was lower than that of the childhood speakers. None of the speakers in the childhood speaker group received an average score lower than 50, indicating that they were perceived as Caucasian Americans. The average score of the speakers in the bilingual group was significantly lower than that of the other two groups. They were consistently rated as Asian Americans.

To investigate which vowels affected listener ratings, pairwise correlation between each speaker's F1 and F2 distances from the average values of the English controls and the rating score was examined. Pairwise correlation between each speaker's Euclidian distance from the average value of the English controls and the rating score was also examined. Tables 14a and 14b show the pairwise correlation results.

Table 14a. The correlation and p values between the F1 and F2 distances from the average values of English controls and the rating score of female speakers. Numbers 2 and 7 on /eɪ/ and /oʊ/ indicate the second and the seventh sub-segments.

Vowel Formants	Pearson's r	p
F1 /ɑ/	0.05546385	0.8641
F2 /ɑ/	-0.1070204	0.7406
F1 /ɪ/	-0.2657851	0.4037
F2 /ɪ/	-0.04964347	0.8782
F1 /i/	-0.4365627	0.1559
F2 /i/	0.1371784	0.6707
F1 /æ/	-0.2442606	0.4442
F2 /æ/	-0.1137809	0.7248
F1 /ɛ/	-0.2509519	0.4314
F2 /ɛ/	-0.2965779	0.3492
F1 /ʊ/	-0.01152707	0.9716
F2 /ʊ/	-0.09996153	0.7572
F1 /u/	0.4097959	0.1858
F2 /u/	-0.5993958	0.03941*
F1 /ʌ/	0.7331982	0.006663*
F2 /ʌ/	-0.439348	0.153
F1 /oʊ2/	-0.4876476	0.1078
F2 /oʊ2/	-0.504369	0.09449
F1 /oʊ7/	0.09302856	0.7737
F2 /oʊ7/	-0.3736678	0.2315
F1 /eɪ2/	0.01676174	0.9588
F2 /eɪ2/	-0.4095133	0.1862
F1 /eɪ7/	-0.06213883	0.8479
F2 /eɪ7/	-0.243717	0.4453

Table 14b. The correlation and p values between the Euclidian distances from the average values of English controls and the rating score of female speakers.

Vowel	Pearson's r	p
/ɑ/	-0.09938825	0.7586
/ɪ/	-0.1649404	0.6085
/i/	0.1318699	0.6829
/æ/	-0.1120859	0.7287
/ɛ/	-0.502807	0.09569
/ʊ/	-0.09124202	0.7779
/u/	-0.5570528	0.05991
/ʌ/	-0.4196431	0.1744
/eɪ2/	-0.4330538	0.1597
/eɪ7/	-0.2489928	0.4352
/oʊ2/	-0.5526692	0.06238
/oʊ7/	-0.3646988	0.2438

Table 14a shows that F2 of /u/ and F1 of /i/ are significantly correlated with the rating score of the female speakers. Negative r value of F2 of /u/ indicate that the less the difference from the average values, the higher score the speakers received. Positive r value of F1 of /i/ indicates that the more the difference from the average values, the higher score speakers received. A multiple regression model was used to analyze the significance of the predictors found in correlation analysis. Three predictors (i.e., F2 /u/, F1 /ʌ/, and F2 /oʊ2/) were selected as variables predicting the rating scores. The two significant predictors were F1 of /ʌ/ (β=0.409, $p < 0.01$) and F2 of the second sub-segment of /oʊ/ (β=-0.061, $p < 0.05$). Unlike the results from the male speakers, Table 14b indicates that none of the Euclidian distances of the vowel is significantly correlated with the rating score of the female speakers.

4.2.3 Performance of the Listeners

Table 15 summarizes the performance of the listeners in their rating. It shows how many listeners correctly identified the ethnicity (i.e., Asian-American or Caucasian American) of the speaker of the presented sound file. The first column provides the percent correct and the second column provides raw scores (i.e., out of 22). The third column gives the number of listeners who achieved each score.

Table 15. Percent correct, raw score, and number of listeners for each raw score in Experiment 2.

Percent Correct	Correct Response (Out of 22)	Number of Listeners
31.82%	7	1
36.36%	8	4
40.91%	9	3
45.45%	10	10
50.00%	11	14
54.55%	12	3
59.09%	13	10
63.64%	14	8
68.18%	15	4
72.73%	16	1
Total		58

Table 15 shows that more than half of the listeners (i.e., 32 out of 58 listeners) performed below chance level (i.e., 50% or lower percent correct). It was initially hypothesized that listener-internal variables such as ethnicity, parent language, extent of interaction with Korean-Americans would predict how they perform in the perception experiment. However, since the majority of the listeners performed below chance level, the prediction of performance scores using listener-internal variables was not considered meaningful. Instead, the performance of the twenty-six listeners who performed better than chance was examined. A multiple regression with scores of the twenty-six listeners as dependent variable revealed that the variables such as the extent of interaction with Korean-Americans and the amount of exposure to Korean culture were not significant predictors (i.e., extent of interaction with Korean-Americans (β=0.028, p =0.891); amount of exposure to Korean culture (β=0.04, p =0.731)).

4.3 Discussion

The results of Experiment 2 show that the majority of the speakers received rating scores in 45-61 range. Some speakers in the male and female English control groups were rated as Asian Americans. Likewise, some speakers in the male and female childhood speaker groups were rated as Caucasian-Americans. Especially noteworthy is that none of the female childhood speakers received scores below 50, indicating that they were rated as Caucasian Americans. These results suggest that the acoustic differences the childhood speakers demonstrate were subtle and hard to perceive.

The subtle acoustic differences seem to have made the perception tasks difficult for the listeners. For both male and female speakers, none of the significant predictors in multiple regression models were found to be significantly different between the speech production of the childhood speakers and the English controls in Experiment 1.

Furthermore, none of the Euclidian distances of the vowel were significantly correlated with the rating score of the female speakers. It suggests that the listeners did not rate the ethnicity of the speakers based on the acoustic differences found in the analysis of the production data. This, in turn, is shown in the below chance-level performance of the majority of the listeners. Due to the low accuracy performance of the listeners, prediction of performance scores based on listener-internal variables was not attempted, even with the listeners who performed at a better than chance level.

However, it should be noted that the average score of the speakers in the female bilingual group was significantly lower than that of the childhood speakers and the English controls. They were consistently rated as Asian Americans. This patterns with the results from Experiment 1 in that more group differences were found in the vowel formants between the English controls and the bilinguals than between the English controls and the childhood speakers. It seems that listeners can accurately identify ethnicity of the speakers when there are enough differences compared to the English control.

5. General Discussion and Conclusion

One of the goals of the current study was to investigate the influence of a heritage language on the production of one's dominant language. In particular, it examines second-generation Korean-Americans' production of English. The results from Experiment 1 revealed that heritage language speakers are different from monolingual

English controls in their vowel production. Their vowel production was also different from that of the bilingual speakers. That is, the childhood speakers' English vowel space was different from that of the English controls and their Korean vowel space was different from that of the Korean controls. The influence of their childhood input was confirmed by the bi-directional changes in the vowel spaces of Korean and English.

The unique speech production of the heritage language speakers can be interpreted in terms of the Speech Learning Model (SLM; Flege, 1995). As mentioned earlier, the SLM postulates a single phonetic space for both L1 and L2. If two systems are separate, vowels of one language do not have to move to accommodate vowels of the other language. According to the SLM, L2 sounds can establish a new category when the phonetic differences of the L1 and L2 sounds are perceived by the speaker. If the differences are not perceived, the L1 and L2 sounds can merge into a single category. The results from the current study show that the female childhood speakers' two front mid vowels (i.e., Korean /e/ and English /ɛ/) occupy the same vowel space, representing a merger between their heritage language and dominant language. That is, their English /ɛ/ was different from that of the English controls and their Korean /e/ was different from that of the Korean controls. This cannot be explained if their Korean and English vowel spaces are separate and do not interact with each other. If the vowel spaces of the two languages are independent, there is no reason for the vowels to be different from that of the monolingual controls. These findings are also in line with the Perceptual Assimilation Model-L2 (PAM-L2; Best and Tyler, 2007) in that some of the Korean and

English vowel categories of Korean-American speakers "re-phonologized" (Best and Tyler, 2007) due to their exposure to the two languages over time. Especially, the Korean /e/ and English /ɛ/ of the female childhood speakers seems to have assimilated based on the acoustic cues they were exposed to. Thus, heritage speakers in the current study demonstrated behaviors similar to that of bilinguals, as their speech production can be interpreted in terms of the approaches developed for bilingual populations.

The results from Experiment 1 also demonstrate that the way male and female speakers exhibit the influence of heritage language in their dominant language is not the same. There was a gender difference in their vowel space adjustment. The male childhood speakers demonstrated fronted English /ɪ, ɛ, æ/ while none of the English vowels produced by the female childhood speakers or the bilinguals were fronted. Instead, the female childhood speakers demonstrated retracted /i, ʌ/ and the bilinguals demonstrated an even larger set of retracted vowels, viz., /i, ɪ, ɛ, æ, ɑ, ʌ/. Thus, both female groups have underutilized low front space relative to the male group.

A comparison of the childhood speakers and the bilinguals revealed the difference in the way they merged vowels. The male childhood speakers had partially merged (i.e., significantly different F2 but merged F1) Korean /e/ and English /ɛ/ and the female childhood speakers demonstrated a complete merger of Korean /e/ and English /ɛ/. However, the bilingual group managed to maintain separate Korean /e/ and English /ɛ/ categories in their crowded front vowel space even though both vowels were retracted compared to the two monolingual controls. The male and female childhood speakers also demonstrated significantly lowered Korean /o/, possibly due to the influence of English /oʊ/. The bilinguals, on the other hand, produced native-like Korean /o/ despite the minimal difference between Korean /u/ and /o/. These results are in line with what has been reported in the bilingual literature in that highly proficient bilinguals make more native-like distinctions (e.g., Guion, 2003). The bilingual speakers in the current study were highly proficient in English and Korean and they demonstrated language-specific category distinctions except for the F2 merger of Korean and English /i/.

Unlike the vowel data, the analysis of voice quality measures did not suggest any systematic pattern among the speaker groups. Furthermore, it was found that both male and female English controls were breathier than the Korean controls. It is possible that the Korean controls produced English /s/ with the influence of Korean tense fricative /s*/ which is known to trigger laryngealized, not breathy, voice. If that were the case, vowels in the context that is free from the influence of preceding consonants might reveal meaningful differences. Further study is needed to confirm this possibility.

The finding that the monolingual English controls have a breathier voice quality than the Korean controls, which is against the initial hypothesis, and the different strategies in vowel production adopted by the male and female speakers raise issues regarding potential factors that could contribute to the acoustic differences found in Experiment 1. One such factor is group identity. It is possible that the different vowel production of the childhood speakers and the bilinguals can be due to the social identity as second-generation Korean-Americans. Previous study on gay, lesbian and bisexual vowel production indicates that vowel production by these individuals might be a learned behavior to express their identity (Pierrehumbert et al., 2004). If so, the acoustic differences found in the current study can also be viewed as a way of expressing their group identity. This hypothesis can also explain the difference between the childhood speakers and the bilinguals as social ties to the heritage community could affect heritage language speakers' speech production (Wong, 2007).

Another potential factor is exposure to non-standard language varieties. Research on the vowels of Mexican Heritage English in the Chicago area revealed that the speakers of this English dialect produced vowels that were different from the non-ethnic regional norm due to the exposure to a different dialect of English (i.e., Mexican Heritage English) in combination with the intent to express their group identity (Konopka and Pierrehumbert, 2008). The exposure to non-standard language varieties is also relevant to the variety of one's heritage language. Early and simultaneous bilingual speakers of English and Korean in the U.S. achieved three-way VOT distinction that is different from late bilinguals and monolingual Koreans due to exposure to their parents' Korean which does not reflect the recent phonetic change that has occurred in Korean (Oh and Daland, 2011). If the exposure to non-standard varieties can affect one's speech production, it is worth investigating the kinds of English and Korean the speakers of the current study were exposed to. The majority of the Korean-American speakers in this study reported that the community they grew up was diverse and that they interacted with people from different ethnic groups. A detailed questionnaire regarding the variety of English and

Korean they were exposed to as well as their social identity would reveal how much the aforementioned factors can affect one's speech production.

The other goal of the current study was to examine whether native English speakers can perceive Korean-American English "accent" and to relate the difference to the existence of "Korean-American English." The results from male speakers indicate that there is more individual variability than group differences. This was also shown by the similar group average scores (i.e., English controls 53.10 vs. childhood speakers 45.72). The female speakers demonstrated more consistent group differences. However, the group average for the childhood speakers was *higher* than that of the English controls (i.e., 61.49 vs. 47.38), indicating that Childhood speakers were rated as Caucasian Americans. On the other hand, the bilingual group was consistently rated as Asian American. The fact that the average scores of all speaker groups except the bilinguals are in the range of 45-61 indicates the perception task was difficult and the listeners did not rate the speakers' ethnicity based on the acoustic differences as evident in the lack of relationship between the acoustic differences found in Experiment 1 and the rating scores in Experiment 2. This is also illustrated in the number of listeners who performed below chance level. Thus, any statistical results mentioned in section 4.2 should be interpreted with caution, including the multiple regression models based on a small number of data points.

The low accuracy in the performance of listeners could be due to the small amount of speech material from each speaker. It is possible that listening to just 10 isolated words was not enough to detect any acoustic characteristics of ethnicity. The results might have been different had the listeners been provided with longer stimuli with a variety of acoustic cues, not only from segments but also from intonation and rhythm. At the same time, it should also be noted that the bilinguals received significantly lower ratings, indicating that they were consistently perceived as Asian Americans. This, in turn, suggests that the bilinguals' speech demonstrated what people perceive as "Asian-American English" or "Korean-American English." The perceived accent in the speech of bilinguals but not the childhood speakers is consistent with the results of Experiment 1, where the bilinguals and the English controls differed on more vowel categories than did the childhood speakers and the English controls. Thus, it is possible that listeners need sufficient number of "off-target" tokens to perceive non-standard English. If so, the acoustic differences that the childhood speakers demonstrate might be just not enough to be perceived as "Asian-American English." What people perceive as Korean-American English may come from the speech of more Korean influence (i.e., bilingual speakers).

In sum, the current study investigated the impact of heritage language on heritage speakers' dominant language. The results revealed that childhood speakers exhibit some acoustic differences that are indicative of heritage language influence. Their vowel production was neither the same as that of monolingual controls nor the bilingual speakers. This study also revealed that the acoustic differences that the childhood speakers exhibit might not be consistently perceptible, unlike the bilingual speakers who were consistently identified as Asian Americans in the perception experiment.

The current study brings different subfields of linguistics together in that this topic can be related to areas such as bilingualism, second-language acquisition, and sociolinguistics. It shows that insufficient childhood input of heritage language can still affect one's dominant language, illustrating the importance of early language exposure. The extension of the current study should include careful investigation of social factors as well as the language varieties the speakers are exposed to. Furthermore, future research should include more speakers in each group so that statistical tests can have more power and the results can be generalized to a larger speech community. Finally, the analysis should be extended to include other cues such as acoustic cues in the consonant as well as prosodic cues such as intonation and rhythm.

Appendix A

Mean values (standard deviations in parentheses) of 8 voice measures of male groups.

	Childhood speaker	English control	Korean control
H1*-H2*	0.75386 (2.85215)	1.62823 (2.66484)	1.438225 (1.890991)
H1*-A1*	12.74374 (3.579958)	14.24944 (3.307623)	15.90865 (2.895785)
H1*-A2*	12.81806 (4.881757)	16.82486 (5.724284)	15.9901 (3.549037)
H1*-A3*	9.33575 (4.519821)	8.95311 (6.010549)	11.42943 (1.995596)
HNR05	13.71464 (4.232836)	14.88612 (7.30892)	25.5698 (9.311181)
HNR15	26.91643 (3.982575)	25.90083 (6.122935)	34.63143 (7.94882)
HNR25	28.91291 (4.179284)	28.36873 (4.909895)	35.12053 (6.953684)
HNR35	31.07198 (3.782425)	29.98762 (4.457148)	35.1112 (5.354322)

Appendix B

Mean values (standard deviations in parentheses) of 8 voice measures of female groups.

	Bilingual	Childhood speaker	English control	Korean control
H1*-H2*	7.4052 (3.844502)	7.462288 (2.04194)	9.11631 (3.247792)	10.55645 (2.772816)
H1*-A1*	15.80897 (2.625337)	13.9212 (3.758411)	17.66256 (4.324712)	15.28128 (1.86946)
H1*-A2*	16.74993 (3.955268)	6.642688 (4.291023)	19.09761 (5.879978)	11.78593 (3.813051)
H1*-A3*	12.79807 (6.393557)	3.950575 (4.252006)	16.07939 (5.624121)	11.26778 (4.69092)
HNR05	29.02358 (10.29158)	34.93749 (10.88448)	22.79806 (7.592325)	34.87047 (8.777319)
HNR15	37.90733 (8.792269)	42.99938 (9.934474)	29.91382 (6.46405)	45.30325 (7.469246)
HNR25	39.9349 (7.526494)	43.65398 (8.576379)	33.38535 (5.78794)	47.71377 (6.311989)
HNR35	39.79142 (6.77433)	42.24554 (7.185756)	34.75745 (5.375632)	48.54057 (5.279826)

References

Ahn, S., & Iverson, G. K. (2007). Structured imbalances in the emergence of the Korean vowel system. *Amsterdam Studies in the Theory and History of Linguistic Science Series 4*, *284*, 275.

Au, T. K. F., Knightly, L. M., Jun, S.-A. & Oh, J. S. (2002) "Overhearing a Language During Childhood", *Psychological Science*. 13, 238-243.

Au, T. K. F., Oh, J. S., Knightly, L. M., Jun, S. A., & Romo, L. F. (2008). Salvaging a childhood language. *Journal of Memory and Language*, *58*(4), 998-1011.

Benmamoun, E., Montrul, S., & Polinsky, M. (2010). White paper: Prolegomena to heritage linguistics. *Harvard University*.

Best, C. T. (1995). A direct-realist view of cross-language speech perception. In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research* (pp. 171–204). Timonium, MD: York Press.

Best, C. T., & Tyler, M. D. (2007). Nonnative and second-language speech perception: Commonalities and complementarities. In J. Munro & O.-S. Bohn (Eds.), *Second language speech learning: The role of language experience in speech perception and production* (pp. 13–34). Amsterdam: John Benjamins.

Boersma, P., & Weenink, D. (2012): Praat: doing phonetics by computer (version 5.3.28) [Computer program]. Retrieved 28 Sept 2012, from http://www.praat.org/.

Caramazza, A., Yeni-Komshian, G. H., Zurif, E. B. & Carbone, E. (1973). The acquisition of a new phonological contrast: The case of stop consonants in French–English bilinguals. *Journal of Acoustical Society of America,* 54, 421–428.

Cheon, S. Y., & Anderson, V. B. (2008). Acoustic and perceptual similarities between English and Korean sibilants: implications for second language acquisition. *Korean Linguistics*, *14*(1), 41-64.

Cho, T., Jun, S.-A., & Ladefoged, P. (2002). Acoustic and aerodynamic correlates of Korean stops and fricatives. *Journal of Phonetics, 30,* 193-228.

de Krom, G. (1993). A cepstrum-based technique for determining a harmonics-to-noise ration in speech signals. *Journal of Speech and Hearing Research, 36,* 254-266.

Epstein, M. (1999). *A comparison of linguistic and pathological breathiness using the LF model*. M.A. thesis, University of California, Los Angeles.

Esposito, C. M. (2010). The effects of linguistic experience on the perception of phonation. *Journal of Phonetics*, *38*(2), 306-316.

Flege, J. E. (1995) Second language speech learning: theory, findings, and problems. In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research* (pp. 229-273). Timonium, MD:York Press.

Flege, J. E., Birdsong, D., Bialystok, E., Mack, M., Sung, H., & Tsukada, K. (2006). Degree of foreign accent in English sentences produced by Korean children and adults. *Journal of Phonetics*, *34*(2), 153-175.

Garellek, M. (2010). *The acoustics of coarticulated non-modal phonation* (Master's thesis). Retrieved from http://www.linguistics.ucla.edu/research/56-ucla-ma-theses.html

Garellek, M., & White, J. (2012). Stress correlates and vowel targets in Tongan. *UCLA Working Papers in Phonetics*, 110, 65-85.

Guion, S. G. (2003). The vowel systems of Quichua-Spanish bilinguals. *Phonetica*, *60*(2), 98-128.

Hillenbrand, J., Getty, L. A., Clark, M. J., & Wheeler, K. (1995). Acoustic characteristics of American English vowels. *The Journal of the Acoustical society of America*, *97*(5), 3099-3111.

Holmberg, E. B., Hillman, R. E., Perkell, J., Guiod, P. & Goldman, S. L. (1995). Comparisons among aerodynamic, electroglottographic, and acoustic spectral measures of female voice. *Journal of Speech, Language, and Hearing Research, 38,* 1212–1223.

Kang, Y. (2003). Perceptual similarity in loanword adaptation: English postvocalic word-final stops in Korean. *Phonology*, *20*(2), 219-274.

Kawahara, H., Masuda-Katsuse, I., & de Cheveigné, A. (1999). Restructuring speech representations using a pitch adaptive time-frequency smoothing and an instantaneous-frequency-based F0 extraction: Possible role of a repetitive structure in sounds. *Speech Communication, 27,* 187–207.

Khattab, G. (2002). VOT production in English and Arabic bilingual and monolingual children. *Amsterdam Studies in the Theory and History of Linguistic Science Series 4*, 1-38.

Klatt, D. H., & Klatt, L. C. (1990). Analysis, synthesis, and perception of voice quality variations among female and male talkers. *the Journal of the Acoustical Society of America*, *87*(2), 820-857.

Knightly, L. M., Jun, S.-A., Oh, J. S., & Au, T. K. (2003). Production benefits of childhood overhearing. Journal of the Acoustical Society of America, 114, 465–474.

Konopka, K., & Pierrehumbert, J. (2008). Vowels in contact: Mexican heritage English in Chicago. In *Symposium about Language and Society-Austin (SALSA), University of Texas at Austin*.

Ladefoged, P. (2001). *A Course in Phonetics* (4th ed.). Boston, MA: Heinle & Heinle.

Mora, J. C., & Nadeu, M. (2012). L2 effects on the perception and production of a native vowel contrast in early bilinguals. *International Journal of Bilingualism*, *16*(4), 484-500.

Newman, M., & Wu, A. (2011). "Do You Sound Asian When You Speak English?" Racial Identification and Voice in Chinese and Korean Americans' English. *American Speech*, *86*(2), 152-178.

Oh, M., & Daland, R. (2011). Stops and phrasing in Korean and English monolinguals and bilinguals. In *Proceedings of the XVIIth Internation Congress of Phonetic Sciences in Hong Kong*.

Oh, J. S., Jun, S. A., Knightly, L. M., & Au, T. K. F. (2003). Holding on to childhood language memory. *Cognition*, *86*(3), B53-B64.

Oh, M. (2012). Adaptation of English complex words into Korean. *Journal of East Asian Linguistics*, *21*(3), 267-304.

Pierrehumbert, J. B., Bent, T., Munson, B., Bradlow, A. R., & Bailey, J. M. (2004). The influence of sexual orientation on vowel production (L). *The Journal of the Acoustical Society of America*, *116*(4), 1905-1908.

Piske, T., MacKay, I. R., & Flege, J. E. (2001). Factors affecting degree of foreign accent in an L2: A review. *Journal of phonetics*, *29*(2), 191-215.

Shue, Y.-L., Keating, P. A., & Vicenik, C. (2009). VoiceSauce: A program for voice analysis. Poster presented at the 158thth meeting of the Acoustical Society of America, San Antonio, TX.

Sjölander, K. 2004. The Snack Sound Toolkit [Computer program]. Retrieved February 3, 2014, from http://www.speech.kth.se/snack/.

Stevens, K. N. (1977). Physics of laryngeal behavior and larynx modes. *Phonetica, 34,* 264-279.

Sundara, M., Polka, L., & Baum, S. (2006). Production of coronal stops by simultaneous bilingual adults. *Bilingualism: Language and Cognition*, *9*(01), 97-114.

Wong, A. (2007). Two vernacular features in the English of four American-born Chinese. *University of Pennsylvania Working Papers in Linguistics*, *13*(2), 17.

Yang, B. (1996). A comparative study of American English and Korean vowels produced by male and female speakers. *Journal of Phonetics*, *24*(2), 245-261.