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Research Article

Maintenance of phonetic and phonological distance in the English and Korean back vowel contours of heritage bilinguals

Andrew Cheng *

Language Science, University of California, Irvine, Irvine, CA, USA

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ABSTRACT

Bilingualism research demonstrates that the potential merger of vowel categories across a speaker's two languages is affected by the age of acquisition of the second language. For heritage bilinguals, however, there is no clear L1 and L2, since they acquire their heritage language in early childhood, but become dominant in the mainstream language of society as adults. Heritage bilinguals may nevertheless will acquire distinct vowel systems in their two languages, rather than a merged system. In this study, the back vowels of California English and Seoul Korean, two varieties that are spoken by bilingual second-generation Korean Americans in California, were collected in natural speech. Formant measurements were analyzed using linear mixed effects regression modeling and generalized additive mixed modeling to see whether the vowels of each language were similar or different in their formant contours. As predicted, the bilinguals maintained distance between the vowels of both languages across their durations, and the phonological effects of coarticulation were found to be stronger in English than in Korean. The differences are attributed to "multicompetence" in heritage bilinguals' phonology (Cook, 2020), or the interrelationship of multiple systems that exist and interact in the bilingual mind without merging completely, in opposition to models that frame heritage bilingualism as inherently imbalanced in favor of the dominant language.

1. Introduction

As memorably demonstrated by Grosjean (1989), a bilingual is "not two monolinguals in one". Grosjean's argument was for a "wholistic" view of bilingualism, in which a bilingual speaker's languages affect one another and create a shared phonological system. However, this does not necessarily mean that the phonemes of both languages are mixed; for example, each language will have its own internal organization of phonological rules that apply differently to the same phonemes. In what ways does a bilingual's phonological system reflect both internal organization and the effects of two languages?

Some evidence from second language acquisition studies indicates that a speaker's native language, or L1, can change in response to acquisition of the second language, or L2 (Flege, 1995). For example, Baker and Trofimovich (2005) studied early versus late Korean-English bilinguals and the effect of age of acquisition on the degree and direction of L1 and L2 vowel system interactions. The early group arrived in the United States[1] from South Korea as children or young adolescents and acquired English at that time, while the late group arrived as adults and acquired English as adults. They found that the early bilinguals' two languages influenced one another more, as determined by an identified merger of the English TRAP and DRESS[2] vowels due to influence from the Korean vowel system. The late bilinguals demonstrated a more unidirectional influence of Korean on English. Not all studies come to the same conclusion, however. Another study found that early Spanish-Quechua bilinguals maintained clearly separate systems of vowels, while the late bilinguals tended to have a more mixed system (Guion, 2003). Even speakers who began acquiring a new language as adults demonstrated changes in the vowel quality of their native language (Chang, 2012, 2013) as has been

* Address: Language Science, University of California, Irvine, 3151 Social Science Plaza A, Irvine, CA 92697-5011, USA.

E-mail address: acheng14@uci.edu

[1] The study was conducted in Illinois, and all of the Korean subjects had only resided in Illinois within the United States (Wendy Baker, p.c.).

[2] These are Wells lexical set words used to represent specific vowel qualities that may be involved in regional variation (Wells, 1982)

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documented in studies of change in vowel quality (Chang, 2013, 2019).

Much of the past research on bilingualism has focused on sequential bilingual speakers who have a clear L1 and L2. However, the literature is lacking with respect to the growing group of bilinguals known as heritage speakers (Valdés, 1999; Polinsky & Kagan, 2007; Polinsky & Scontras, 2020). Heritage speakers often either learn two languages (one from a caregiver and one that is spoken broadly in society) simultaneously or learn a home language as children and switch to the societally dominant language upon entering school. Research in the phonetics and phonology of heritage speakers finds them patterning with native monolinguals in some respects, but diverging from them in others (Chang, 2020).

While much of the research on heritage bilinguals is built on the theorization of incomplete acquisition of the heritage language, it is important to note the disadvantages of the rhetoric of incompleteness (Kupisch & Rothman, 2018), including the fact that heritage speakers have often been shown to have fully acquired a "native-like" phonological patterns in their heritage language, even if their morphosyntactic grammars are not native-like (Chang, 2020). Thus, if heritage speakers' phonological acquisition is complete before they switch to dominance in the mainstream language of society, then they should be less likely to demonstrate influence of the mainstream language on their heritage language. Yet at the same time, their use of the mainstream language may not be equivalent to that of strict monolinguals, either.

Because heritage speakers' speech varies widely, it is difficult to draw broad conclusions about the entire group. Despite this, the literature does contain suggestive evidence that heritage speakers demonstrate influences of the dominant language (i.e., English) on the pronunciation of heritage language phonemes (Knightly et al., 2003; Godson, 2004) and the ability to differentiate both language-internal and cross-linguitic contrasts in consonants and vowels. Chang et al. (2011) argue that although some kind of bidirectional influence of the two languages in the heritage phonological system exists, the early age at which heritage speakers acquired their heritage language helps them maintain both functional, language-internal contrast (e.g., *boot* vs. *boat*) and non-functional, cross-linguistic contrast (e.g., English /u/ vs. Korean /u/), without merging their systems (Chang et al., 2011:3974). This is one aspect of the "multicompetence" view of bilingualism and multilingualism (Chang, 2019; Cook, 2003, 2020), whereby two languages in a bilingual system restructure one another rather than simply exist in tandem. Multicompetence is increasingly being understood as an important framework for understanding the phonetic, phonological, and cognitive differences in language production and processing between different types of bilinguals: if what we know about bilingual phonetic and phonological organization comes only from "balanced" bilinguals or L2 learners rather than variably multicompetent speakers, then what we know is incomplete.

In the following sections, I describe the rationale for studying the contrast between back vowels in English and Korean, followed by background information about Korean Americans as speakers of English and Korean.

1.1. Sound change and the back vowels of California English and Seoul Korean

Past research has indicated that young heritage speakers may participate in sound changes to a smaller degree than their native speaker counterparts (Kang & Nagy, 2016), but also that heritage bilinguals may resist local sound changes in the majority language (e.g., English (Tse, 2019)). Two sound changes affecting the back vowels of English and Korean are under consideration here, which bilingual Korean Americans may or may not participate in.

The back vowels in California English include /u, ʊ, oʊ, ɑ/[3], while the back vowels of Seoul Korean are /u, ɯ, o, ʌ[4]/; the Korean /ɐ/ is central rather than back. Notably, both English and Korean have a high back rounded vowel /u/, but the English mid-high vowel /oʊ/ is a diphthong, while its Korean counterpart /o/ is a monophthong.

All these vowels are undergoing change, as documented in their primary speech communities. In California English, back vowels are fronting as part of the California Vowel Shift (Kennedy & Grama, 2012). It has been studied extensively within California (Hinton et al., 1987; Hagiwara, 1997; Bucholtz et al., 2007; Hall-Lew, 2011; Podesva, 2011; Podesva et al., 2015; D'Onofrio, 2015), as well as in other areas in the western half of North America. Dialectal research that specifically focuses on the change in low back vowels (the COT-CAUGHT merger) and its effect on front lax vowel retraction describes it as "Low Back Merger Shift", the "Canadian Shift", or the "Elsewhere Shift" (see Stanley (2020:14-28) for an extensive review), while other research characterizes the California Vowel Shift as a reorganization of the entire vowel space (D'Onofrio et al., 2019).

The fronting of all high back rounded vowels was first discussed in Luthin (1987) and Hinton et al. (1987). Fronted manifestations /u/ and /oʊ/ were particularly salient in the burgeoning stereotype of the California "Valley Girl": a young white woman from the San Fernando Valley region of Southern California (Eckert, 2008). Beyond the young, white, and female stereotype, however, the phenomenon of back vowel fronting appears to have spread to Californian speakers of non-white ethnicities, such as Chicano English speakers in Los Angeles (Fought, 1999) and second-generation Japanese Americans in the Central Valley (D'Onofrio & Van Hofwegen, 2020). As vowel classes may take on multiple significations, fronting may also index a more generalized urban coastal identity (Podesva et al., 2015). Korean Californians, for their part, have previously been shown to participate in some aspects of the California Vowel Shift but resist others. The resistance is suggested to be a result of the influence of Korean phonology on English vowels (Kim & Wong, 2020).

In Seoul Korean, there is evidence that a chain-like vowel shift may be underway that has caused /o/ to lower its F1 and raise to become more like /u/, which is in turn may be becoming more fronted (Kang and Kong, 2016). In comparison to the sound change present in California English, it is the F1 (height) of the /o/ vowel that is undergoing a shift, rather than

[3] /ɔ/ is merged with /ɑ/ in California English due to the COT-CAUGHT merger (Kennedy & Grama, 2012).

[4] Note that the Korean /ʌ/ is generally more posterior in articulation than the (central) English /ʌ/.

the F2 (backness). More research is necessary to determine the extent of this sound change and whether it has been transmitted to the younger generation of heritage Korean speakers who have limited exposure to the language.

Given the parallel (but not equivalent) sound changes occurring in the high back vowels of both languages, English-Korean bilinguals who speak Korean as a heritage language present a unique opportunity to examine how vowels that are in flux are organized within a native or "native-like" bilingual system, as well as whether heritage bilinguals participate in ongoing sound changes in both languages.

1.2. Korean Americans as heritage bilinguals

Not all Korean Americans are bilingual in Korean and English. Those who do speak Korean tend to vary between simultaneous and sequential bilingualism, mostly depending on their age of arrival to the United States. Korean Americans who were born and raised in the United States to immigrant parents, known as "second-generation" Korean Americans, tend to be simultaneous bilinguals, hearing English and Korean from their caregivers and immediate environment since birth. Other second-generation Korean Americans are first exposed to English when they enter preschool or school, prior to five years of age. Their L1 is Korean, but they become dominant in English as they assimilate to an English-language schooling system. Heritage speakers' use of the heritage language is not the same as non-heritage monolinguals' use of the language (whether this is due to attrition, incomplete acquisition, or some other mechanism is open to debate).

For these English-Korean bilinguals, the question of which language is the L1 is debated (Montrul, 2010), as is whether the traditional classification of L1 and L2 even holds water. All heritage speakers could be considered "early bilinguals", but the heritage language experience is radically different from sequential bilingualism as in the case of, for example, students who begin learning a second language as an elective course of study in school, or even in primary school, or adults who relocate to a foreign country and begin learning a new language under an immersive context. Yet many heritage speakers fall below the threshold for proficiency in morphosyntax, lexicon, and other levels of grammatical organization in their heritage language, excepting phonetics and phonology (Chang, 2019), which makes it difficult to equate them with simultaneous bilinguals who acquire two languages in a fully bilingual and diglossic context.

Thus, heritage bilingual Korean Americans from California are an interesting case study for an examination of bilingual phonological organization. If they are participating in the back vowel fronting sound change of the California Vowel Shift, which recent research has demonstrated (Cheng, 2019; Kim & Wong, 2020), then does this change in the dominant language reorganize the phonemes of heritage Korean? Conversely, does the potential raising of Korean /o/, or its status as a monophthong, affect the height or formant contours of their English /oʊ/? Or do heritage bilingual speakers maintain separate targets for these similar vowels?

In the current study, I examine heritage speakers of Korean, specifically young adult Korean Americans who identify as second-generation and are bilingual in Korean and English. Because of their early simultaneous acquisition (like the early bilinguals in Baker and Trofimovich (2005)), heritage bilinguals should be able to maintain phonological contrasts between their vowels in Korean and English, despite some overlap in the phonemes of each inventory. I focus on the organization of high back vowels in Korean and English, taking into account the ongoing shifts in the production of English /oʊ/ and /u/ and Korean /o/ and /u/.

The predictions are as follows:

(1) The F1 and F2 values of English and Korean /u/ will differ, with a higher magnitude of raising in English (due to the California Vowel Shift) than in Korean (as a consequence of Korean /o/-fronting).

(2) Similarly, English /oʊ/ and Korean /o/ will differ because /oʊ/ is a diphthong whose F2 increases over the duration of the vowel.

(3) Finally, because of the California Vowel Shift, English vowels that occur adjacent to segments that induce strong coarticulatory effects will show different contours. For example, a "dark" /l/ in syllable coda position may lower F2 of preceding English vowels and counter the fronting effect of CVS (Sproat & Fujimura, 1993), while the coronal consonants /t, d, n, s, z/ in syllable onset position may raise F2 (Fridland & Kendall, 2017; Havenhill, 2019). Coarticulatory effects for Korean vowels should look different due in part to the absence of the California Vowel Shift in Korean, as well as to slight differences in the place of articulation for consonants of the same class (e.g., Korean coronals may be more anterior than English coronals (Ko, 2013), leading to higher F2 for following vowels.)

2. Method

2.1. Participants

Twenty-one second-generation Korean Americans born and raised in California participated in this study. Twelve identified as female, and nine as male. Participants ranged in age from 18 to 36 years old (mean = 24.7 ± 4.6 years). Eighteen had been raised in Southern California, two in Northern California, and one in both regions. Every interviewee was conversationally fluent in English and Korean and had at two Korean parents, at least one of whom was born and raised in Seoul, South Korea. Most participants reported learning Korean at home as their first language, then acquiring English soon after, either at home, in their neighborhoods, or at school once they reached schooling age. Two participants reported English as their first language, and only one reported use of only English in their childhood; all other interviewees reported use of only Korean or a mix of Korean and English with their family and caregivers. Further demographic information about the participants can be found in Table 1.

Participants sat for a bilingual sociolinguistic interview designed to elicit natural conversational speech in the two languages. Data was collected in 2017 and 2018 in various locations throughout Northern and Southern California. Interviewees were recruited through a combination of personal connections, fliers posted around university campuses, and advertisements through email newsletters and social media that described a study of bilingualism and language attitudes specifically for Korean Americans who were able to read and speak English and Korean.

Table 1
Demographic information for 21 second-generation Korean American interviewees.

Gender	number	Age range	Age mean
Female	12	19–36	25
Male	19	18–29	24
Total	21	18–36	24.67 ± 4.62

2.2. Procedure

Five bilingual interviewers, including the author, were trained in standard sociolinguistic interview procedures (Becker, 2013), and the modified procedure for this project. Interviewers were a mix of Korean Americans and other Asian Americans who varied in gender and age; all were proficient in spoken Korean and English.

Interviewees were introduced and welcomed to the laboratory or recording space in a mix of English and Korean. Then, the interviews always began with the interviewer asking, in Korean, for the interviewee to give a short self-introduction. This was followed by more questions, in Korean, about the interviewee's background, family, and hobbies. At the conclusion of the Korean interview, the interviewer asked the interviewee to read some Korean text on a document containing four short narratives written in *hangul*, the Korean writing system. Next, the interviewer switched to English and asked the interviewee to read sign research-related documents. The interview then continued in English, with questions more specific to the interviewee's experiences with language, ethnic identity, and Korean culture. Interviewees were allowed to code-switch between Korean and English at any time, and they were also allowed to skip any question they did not wish to answer.

The Korean portion of the sociolinguistic interview lasted 4 to 16 min (mean = 10 ± 3 min), and the English portion lasted 8 to 52 min (mean = 33 ± 11 min). Data from the reading portions are not used in this analysis. Interviewees were compensated monetarily for their contributions.

2.3. Data processing

Four native Korean speakers who did not participate in the interviews rated a randomized one-minute sample of speech from each participant's Korean interview on two 5-point Likert scales for strength of accent in Korean and level of proficiency in Korean. For the level of accent, raters answered the question, "How much do they sound like a native speaker during their interview?" on a scale from "sounds exactly like someone from Korea" to "sounds like Korean is not their first language." For the level of proficiency, raters answered the question, "How much ease does the speaker have speaking in Korean during their interview?" on a scale from "no problem whatsoever communicating" to "clearly struggling to communicate ideas". Five independent raters also rated a randomized one-minute sample of speech from each participant's English interview on similar 5-point Likert scales for level of "non-native" accent and proficiency in English. Only participants who scored below 3 on both scales were to be excluded from analysis; none of the 21 current participants were excluded for this reason.

The interviews were transcribed manually using the TextGrid function of Praat (Boersma and Weenink, 2016). Each TextGrid had four tiers, one for each combination of speaker (interviewer and interviewee) and language (Korean and English). All intelligible speech was transcribed as heard, including stutters, speech errors, instances of code-switching, and novel words or non-words, all of which were included in a customized pronunciation dictionary for the purposes of forced alignment. Laughter, coughs, and other non-speech sounds were excluded so that the forced aligner would skip them.

Phones in the TextGrids were force-aligned to two-channel audio using the Penn Forced Aligner in English (Yuan & Liberman, 2008) and kp2fa in Korean (Yoon & Kang, 2012), via a wrapper function created for the Berkeley Phonetics Machine (Sprouse & Johnson, 2016). This allows individual segments and words from the transcript to be matched to their place in the audio file with great efficiency, though not without some computer-generated error. For example, overlapping and simultaneous speech was included in the TextGrid transcriptions, with the reasoning that as most of the interviews were recorded in two channels, the forced aligner would be directed to the correct channel for each speaker. However, some amount of signal overlap will have contributed to errors in alignment. Any alignment errors discovered during processing were hand-corrected and re-aligned, though it was not deemed possible to catch every error.

Formant and fundamental frequencies were tracked using a series of scripts employing IFC Formant (Ueda et al., 2007) at 10-millisecond intervals throughout the entire recording. To mitigate the effects of the outliers generated by the tracker and mis-aligned phones, the raw measurements (per participant) were treated using the `smoothn` module (Garcia, 2010) with a smoothing parameter of 10 and robust smoothing. Because the automatic formant extraction script selected formant measurements at set timepoints within a vowel, occasional formant tracking errors may have been amplified, producing "spiked" trajectories as can be seen in Fig. 1a.

Smoothing of the raw data was necessary to minimize the influence of these outliers and tracking errors (Fig. 1b). In addition to producing more reliable contour shapes for visible analysis, smoothing also created better conditions for the generalized additive mixed model analysis.

Data cleaning continued with the exclusion of obvious tracking errors (e.g., f0 of 0 Hz during vowels) and outliers. Hertz values were converted into Bark, an auditory scale, and then log-transformed to normalize between participants. Finally, the following tokens were removed from the data: code-switched words (e.g., Korean words uttered during the English interview or vice versa), unstressed vowels of English (due to the possible effects of vowel reduction (Moon & Lindblom, 1994), and tokens in both languages that followed the palatal glide /j/ (due to the coarticulatory effects of diphthongs such as *you* and triphthongs such as *yo*).

The final dataset used in statistical analysis contained 152,400 observations, representing 15,240 tokens of six vowels from 21 speakers, and ten smoothed and normalized F1 and F2 values per token.

2.4. Data analysis

The dependent variables were the first and second vowel formants (F1 and F2). Two types of statistical analysis were

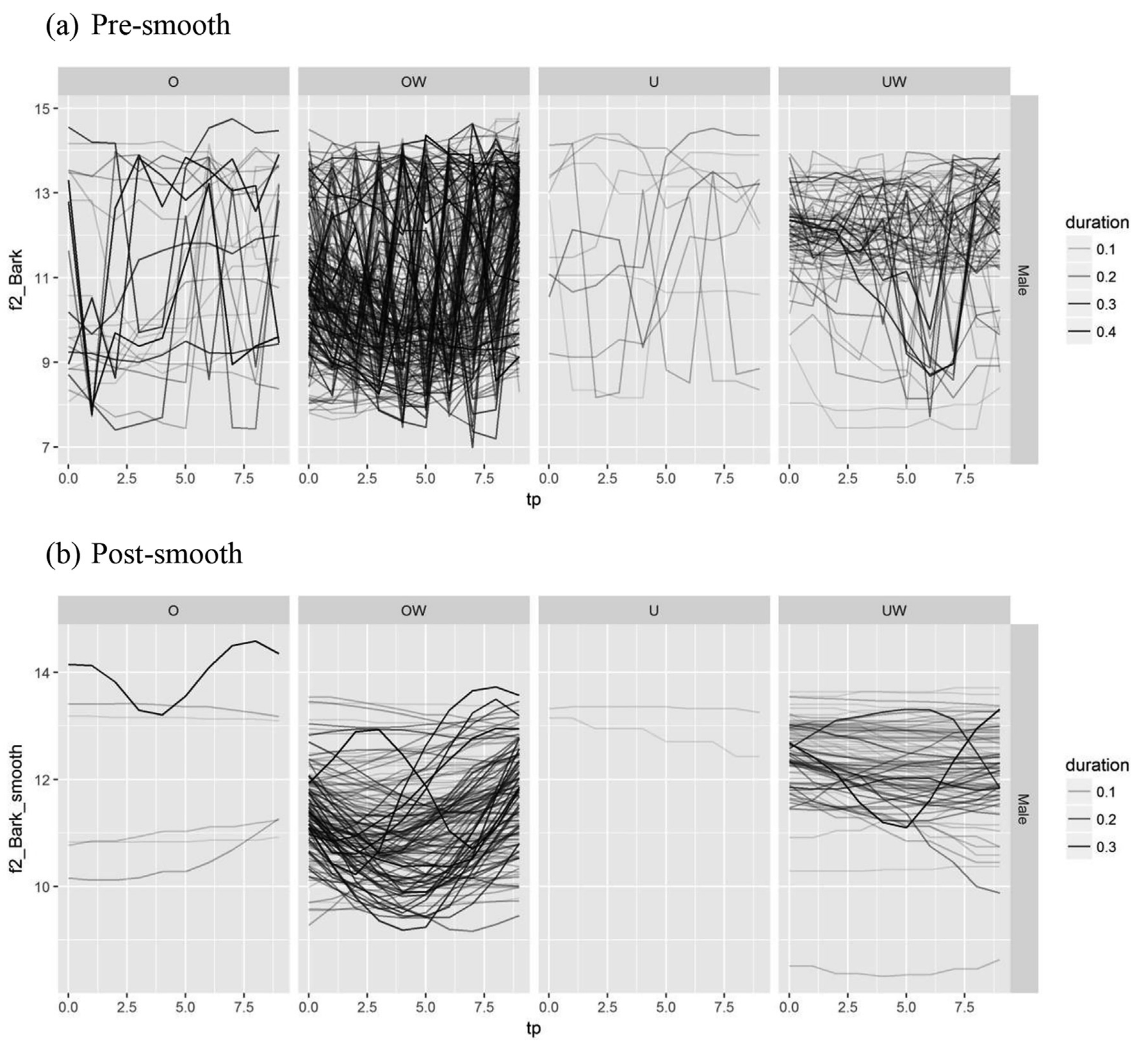

Fig. 1. Sampled data demonstrating F2 trajectories (Bark) taken at ten equally-spaced timepoints per vowel from the raw (unsmoothed) data (a) and the smoothed data (b). In (a), occasional formant tracking errors were amplified by the selection of formant values at timepoints (instead of, for example, using mean values), which complicated the analysis. In (b), formant tracking errors that created outlier points were "smoothed out", producing more reliable trajectory shapes.

performed on each vowel formant separately. The first was linear mixed effects regression modeling. The models were fit to the single F1 and F2 values taken near the midpoint of each Korean vowel and each stressed English vowel (timepoint 4 out of 10). With one measure per vowel token, there were on average 195 (sd = 121) tokens of English /oʊ/, 83 (sd = 53) tokens of English /u/, 124 (sd = 65) tokens of English /ɑ/, 89 (sd = 56) tokens of Korean /o/, 43 (sd = 26) tokens of Korean /u/, and 192 (sd = 99) tokens of Korean /ɐ/ per speaker. The second type of analysis was generalized additive mixed modeling, which used ten measurements from each vowel, or ten times as many tokens as the linear model. The variance in the number of tokens was very high, due to the large variance in the amount of time each participant spent speaking in each language. However, the use of non-parametric statistical tests such as linear mixed effects regression and generalized additive mixed modeling (e.g., Sóskuthy, 2021), as well as the inclusion of random effects and random smooths prevents the imbalance in sample size from affecting the robustness of the model results. (Further detail about the models will be given in Sections 3.2 and 3.3)

3. Results

3.1. Visual analysis

In all figures, analyses, and discussions, the English mid-high back round vowel will be represented interchangeably as "OW"[5] or /oʊ/, and the English high back round vowel will be represented as "UW" or /u/. The Korean back vowels will be represented as "O" or /o/ and "U" or /u/. When the mid-high vowels of both languages are discussed as a pair, I will use "OW/O"; and when the high vowels of both languages are discussed as a pair, I will use "UW/U".

The normalized F1 measurements of Korean versus English back vowels can be seen in Fig. 2a. Only measurements from vowel midpoints are plotted. All six vowels appear to maintain distance from one another. That is to say, the median

[5] "OW", "UW", "AA", and other ARPABET notation is used by many forced alignment programs due to the ease of encoding using common characters; each ARPABET symbol (or digraph) has a corresponding symbol in the International Phonetic Alphabet. Note that the Korean ARPABET symbols correspond to the Korean vowels, not the single-character version of ARPABET for English vowels.

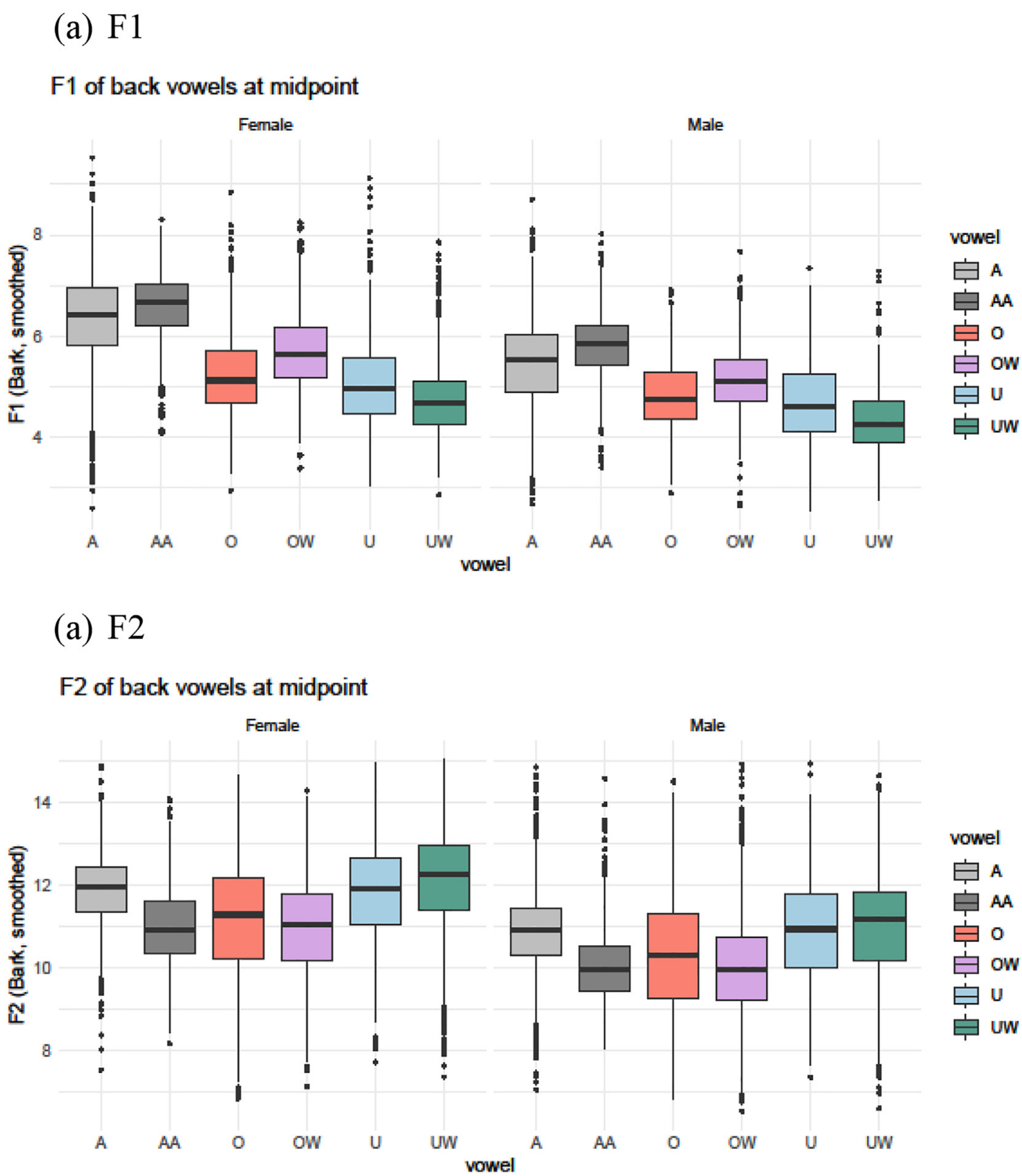

Fig. 2. For the vowels English /oʊ/ (OW), English /u/ (UW), Korean /o/ (O), and Korean /u/ (U), with English /ɑ/ (AA) and Korean /ɐ/ (A) for comparison, in English-Korean bilinguals: (a) Bark F1 at vowel midpoint, split by speaker gender, and (b) Bark F2 at vowel midpoint, split by gender.

F1 measurements are all different from one another, except for Korean /o/ and /u/. In addition, English /oʊ/ has a greater overall F1 than Korean /o/, and English /u/ has a lower overall F1 than Korean /u/.

The results for F2 measurements can be seen in Fig. 2b. F2 of /oʊ/ and /o/ is lower than F2 of /u/ in English and Korean. When compared to the low vowels (English /ɑ/ and Korean /ɐ/), a dual pattern emerged. Both high back vowels pattern with Korean /ɐ/ in terms of F2, while both mid-high back vowels pattern with English /ɑ/. This is especially pronounced in male speakers, in what looks like a coalescence of the “back” vowels into two categories: back (“O”, “OW”, “AA”) and central (“U”, “UW”, “A”).

In Fig. 3, the smoothed timepoint data (at points 1, 3, 5, 7, and 9) are plotted on a standard F1-F2 vowel chart on the Bark scale to visualize the two-dimensional trajectories, or contours, of the vowels. To demonstrate the effects of coarticulation, this figure also separates the vowel by specific phonological contexts: pre-lateral, post-coronal, pre-lateral and post-coronal (e.g., *tool*), and elsewhere[6]. Korean /u/ has the most static two-dimensional contour of all four of the vowels in question, while all of the English vowels have large, parabolic contours. Indeed, Korean “U” has a small parabolic shape, but it is smaller than the parabolic shape for Korean “A”, which is uncontestably a monophthong. On the other hand, English “OW” decreases in F2 before increasing again, especially compared to English “AA”, which has a thin parabolic shape but is also a monophthong. These contours will be addressed in the generalized additive mixed model analysis section.

[6] In the OW/O group, there were 152 post-lateral, 2811 post-coronal, 155 post-coronal and post-lateral, and 2867 elsewhere tokens. In the UW/U group, there were 316 post-lateral, 971 post-coronal, 84 post-coronal and post-lateral, and 1276 elsewhere tokens.

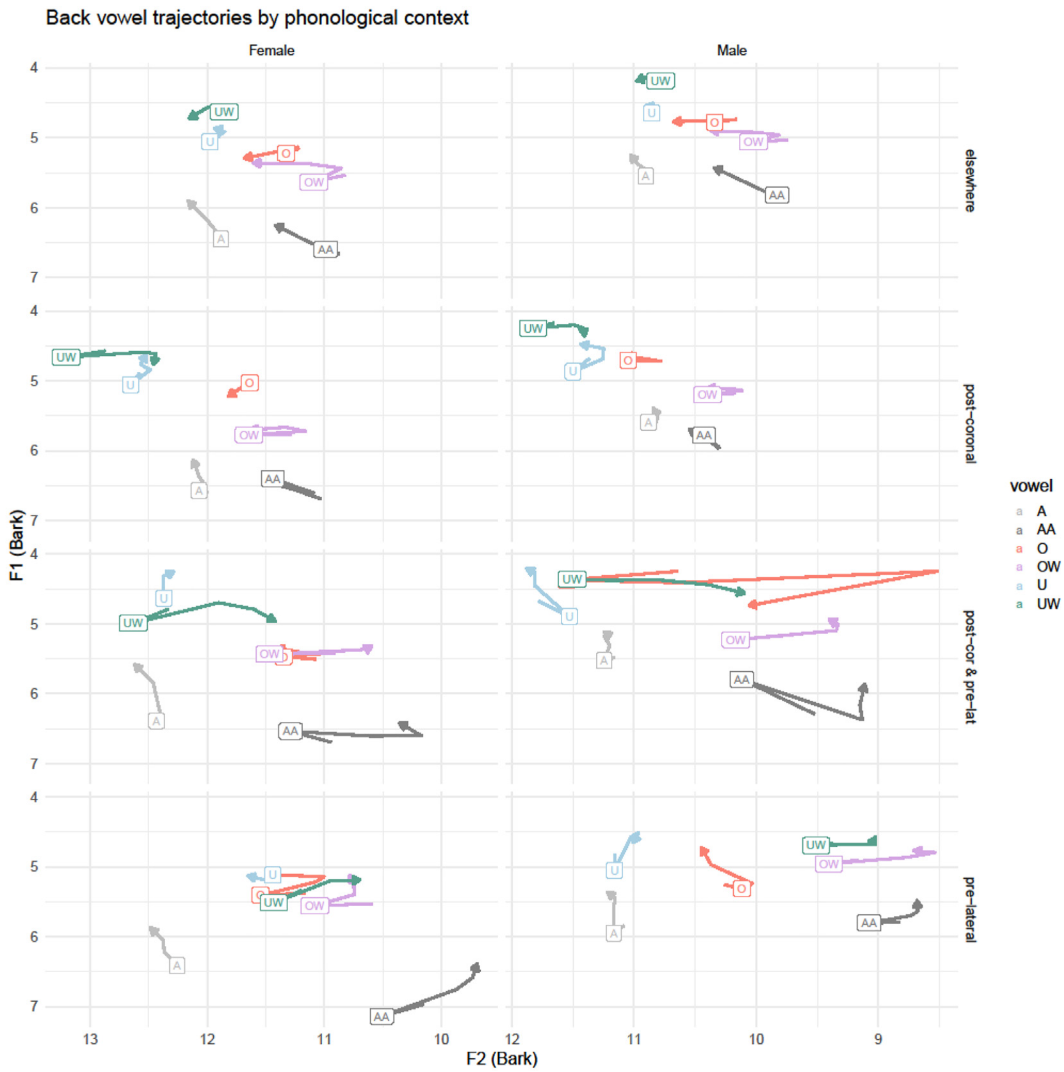

Fig. 3. Vowel trajectories of /oʊ/ (OW), English /u/ (UW), Korean /o/ (O), and Korean /u/ (U), English /ɑ/ (AA), and Korean /ɐ/ (A), with pre-lateral back vowels separated, split by speaker gender.

The effect of neighboring segments on the vowel quality and contour is observable in Fig. 3. Occurrences of each vowel that were followed by lateral segment (/l/)[7] are plotted at the bottom. Korean "O" and "U" have roughly the same F2 contours as their elsewhere counterparts. However, English "OW" and "UW" start off at a lower F2 in the pre-lateral condition and continue to decrease throughout the trajectory of the vowel. The effect of the post-vocalic lateral consonant is present for English but almost completely absent for Korean. On the other hand, the post-coronal context shows increased F2 for all four high back vowels in English and Korean. Finally, the post-coronal and pre-lateral context reveals what appears to be a combination of fronting and backing, leading to relatively long contours for all vowels (except Korean "U"). Thus, an investigation of the immediately neighboring phonemes is included in the statistical analyses in the following sections.

3.2. Linear regression analysis

For the linear mixed effects regression analysis, the mid-high vowels and the high vowels were analyzed separately, due to the different directionality of the patterns observed for each vowel pair. The English mid-high back rounded vowel /oʊ/ and the Korean mid-high back vowel /o/ were subject to one analysis, and the high back rounded vowels of both languages were subject to another analysis. A base linear mixed effects regression model was fitted on the formant values at a midpoint (the value for the fourth timepoint, out of ten, in smoothed Bark) of a vowel "pair".

The base models tested for the effects of gender and the phonological context (pre-lateral, post-coronal, post-coronal and pre-lateral, and elsewhere), with a random effect of participant to account for the hundreds of repeated tokens per participant. Note that each base model does not assume that the vowels come from different languages; the test models will

[7] Determination of a pre-lateral vowel was done solely by categorizing vowels that were followed by an /l/ in running speech and thus did not distinguish between a true syllable-final /l/ as in *coal* and an /l/ that served as the onset of a following syllable or even word, as in *colinear* or *so like*. The /l/-darkening effect in English is not solely limited to syllable-final /l/, as some research has documented it occurring across morpheme and word boundaries and at syllable onsets (cf. Oxley, Buckingham, Roussel, & Daniloff, 2006, Lee-Kim, Davidson, & Hwang, 2013, and Turton (2017) for case studies of American and UK English).

test for this with language as a fixed effect. The Restricted Maximum Likelihood Estimation (`REML`) was set to `FALSE`, because the base model and the comparison models would have different fixed effects.

The first test model included the same effects as well as language, to test whether adding the language of the vowel (English or Korean) improved the accuracy of the model in predicting the formant measurement. The second test model further included an interaction effect between language and phonological context, since coarticulatory effects on vowel fronting such as the F2-lowering effect of a following lateral segment may be present in English but not in Korean.

The models were compared using Likelihood Ratio Tests (base model compared to the first test model, then the first test model compared to the second test model) using the `anova()` function in R (Winter, 2013). Including language improved three of the four models, with p-values well below 0.05 and decreases in AIC values (Table 2). For the models of F2 of OW/O, however, the interaction effect between language and phonological context did not improve on the model with language alone. On the other hand, the model of F2 of UW/U needed to include the interaction effect, as the model with language alone did not improve over the base model, but the second test model did. This could be the effect of the following lateral on vowel F2 in English, which does not occur in Korean (e.g., /u/ in English *pool* would have a lower F2 than usual, but the presence of a syllable-final /l/ in Korean does not significantly lower an already low F2).

Finally, I used a simultaneous General Linear Hypothesis Test (via the package `multcomp` in R) to conduct a post-hoc Tukey's test on the means from the language*phonological context models. This would test whether, when taking both language and phonological context into consideration, English /oʊ/ and Korean /o/ had statistically significant differences in mean F1 and F2 (and the same for English /u/ and Korean /u/). Three of these tests were judged to be significant: F1 of OW/O (estimate = −0.33, z = −13.56, p < 0.001), F2 of OW/O (estimate = 0.20, z = 4.64, p < 0.001), and F1 of UW/U (estimate = 0.43, z = 10.94, p < 0.001). The language comparison for F2 of UW/U, however, was insignificant (estimate = 0.03, z = 0.46, p = 0.65). In other words, Korean /o/ differs significantly from English /oʊ/ in F1 and F2, and Korean /u/ has greater F1 than English /u/, while Korean /u/ and English /u/ are similarly fronted in all contexts (with the notable exception of male speakers' pre-lateral English /u/). However, these tests still only examine the vowels at a midpoint, and the stark change in formant values over the duration of the vowels motivates the use of generalized additive mixed models to analyze formant contours.

The final version of the model, the second test model that included the language*phonological context interaction, can be found in Table 2.

3.3. Generalized additive mixed model analysis

In California English, the mid-high back rounded vowel /oʊ/ is a diphthong whose F2 value changes over the course of the vowel, sometimes non-linearly (Fox, 1983). For this reason, a statistical analysis of only the midpoint of the vowel does not accurately capture the dimensions of difference between English /oʊ/ and Korean /o/. Linear mixed effects regression models are designed to model a pattern in the data with normally distributed variance. But if bilingual Korean Americans' English /oʊ/ is less diphthongized than typical California English due to influence from Korean (or, conversely, whether their Korean /o/

Table 2
Linear mixed regression model comparisons; base models for mid-high back rounded vowels' F1 and F2, and high back rounded vowels' F1 and F2, followed by the models that included language and the models that included an interaction between language phonological context ("phontext"). The Chi-squared and p-values were calculated from comparisons of each model to the one in the row immediately above it.

Vowel	Formant	Fixed effect(s)	npar	AIC	Chisq	Pr(>Chisq)
/oʊ/, /o/ (OW/O)	F1	Base	7	12,210		
		Language	8	11,878	334.6	<0.001***
		Language*phontext	11	11,868	16.22	0.001**
	F2	Base	7	18,926		
		Language	8	18,876	52.304	<0.001***
		Language*phontext	11	18,875	6.7029	0.08199
/u/, /u/ (UW/U)	F1	Base	7	5731.9		
		Language	8	5618.4	115.49	<0.001***
		Language*phontext	11	5589.1	35.279	<0.001***
	F2	Base	7	8014.9		
		Language	8	8016.3	0.5833	0.445
		Language*phontext	11	7996.0	26.338	<0.001***

Base model code[1] (R):

```
base_lm_O_F1 <- lmer(f1_Bark_smooth_4 ~
      Gender +
      phontext +
      (1|Participant),
    data = dfw[dfw$vowel %in% O,], REML=FALSE)
```

Final model code (R):

```
final_lm_O_F1 <- lmer(f1_Bark_smooth_4 ~
      Gender +
      phontext +
      language +
      language*phontext +
      (1|Participant),
    data = dfw[dfw$vowel %in% O,], REML=FALSE)
```

[1] For UW/U, O would be replaced with U, and for F2, F1 would be replaced with F2.

is more diphthongized due to influence from English), this pattern is unlikely to be linear or normally distributed.

To that end, the generalized additive mixed model, or GAMM (Winter & Wieling, 2016; Wieling, 2018), is a more appropriate tool to analyze and compare formant contours. GAMM is essentially a regression model that adapts to non-linear patterns and is ideal for analyzing change over time, such as the contours observed in Fig. 3. Following the methods outlined in Sóskuthy (2017, 2021), Wieling (2018), Gahl and Baayen (2019), and Stanley (2020), I used the `mgvc` package in R (Wood, 2017) to build GAMMs that predict F2 of a vowel and the `itsadug` package (van Rij et al., 2020) to test and visualize the models.

The first GAMM was a base model that only included language and speaker gender as parametric terms (or fixed effects). Although the final linear mixed effects models created in the previous section included the phonological context and an interaction effect of following segment and language, the GAMM models have simplified the analysis in two crucial ways.

First, only F2 was modeled and analyzed. The models for F1 were run, but not analyzed in detail, since the movement trajectory of the English diphthongs tends to be along the F2 dimension, or "horizontal" axis. Change in F2 within the duration of these back vowels is expected to be observed to some degree, while change in F1 is not. Second, the fixed effects of language, gender, and phonological context were combined into one parametric term with eight levels to create a three-way interaction, rather than calling on each term alone and with each of its interactions, as is the case with linear mixed effects regression (Stanley, 2020). The combined parametric term, coded as `GLP`, was used as both a parametric term in the base model, and then also as the smooth term on timepoint (`tp`) in the test model. The result is a model that allows each curve for gender, language, and phonological context to be independent of the others.

In addition, log-transformed vowel duration was included as a parametric term (to control for the fact that shorter vowels may be reduced), word as a random smooth, and speaker as a random smooth, as is common practice with GAMM models of vowel production data (Sóskuthy, 2021). Random smooths here (indicated by `s(tp, participant, bs="fs"), m=1`) are roughly equivalent to random effects in a linear mixed effects regression (indicated by `1|participant`).

Then, I controlled for possible autocorrelation effects in the model by creating an AR1 model (an autoregression model used with time series) and updating the base model to correct the residuals.

The base model was run using the `bam()` function in `mgcv`, with the following formula:

```
gam.0.base.seed <- mgcv::bam(f2_Bark_smooth ~
        GLP + duration_log * GLP +
        s(tp, k=9) +
        s(word, bs="re") +
        s(tp, participant, bs="fs", m=1),
    data=dfo, discrete=TRUE)
  rho <- start_value_rho(gam.0.base.seed)
  gam.0.base <- update(gam.0.base.seed, rho=rho,
  AR.start=dfo$start.event)
```

Note that this model includes a smoothing terms for the vowel timepoints, which is the dimension that helps the model calculate the F2 measurements over the timepoints (`tp`) of the vowel with a non-linear effect, but it does not include the `GLP` parametric term. The code for the test model included the line `s(tp, by=GLP, k=9)`, which represents the smooth term crossed with the combined parametric term `GLP` so that each curve can be independent. The number of "knots" (`k`) in the smooth term was set to nine, one fewer than the ten timepoints in each vowel at which measurements were taken. The code below shows one of the two test models for F2.

```
gam.0.test.seed <- mgcv::bam(f2_Bark_smooth ~
        GLP + duration_log * GLP +
        s(tp, by=GLP, k=9) +
        s(word, bs="re") +
        s(tp, participant, bs="fs", m=1),
    data=dfo, discrete=TRUE)
  rho <- start_value_rho(gam.0.test.seed)
  gam.0.test <- update(gam.0.test.seed, rho=rho,
  AR.start=dfo$start.event)
```

As with the linear mixed effects regression models, I used model comparisons (with `compareML()`) to judge the model fit against model complexity regarding the base GAMM model versus the test model, which included the smooth term for timepoint. Table 3, which lists the results of the model comparisons for both vowels, shows that the test model for OW/O is an improvement over the base model (p < 0.001), which indicates that the three-way interaction included in the test model is significant.

The final model's predictions for F2 of OW/O are visualized in Fig. 4a. The contours for OW/O F2 clearly follow a parabolic shape, generally starting high, decreasing to about the midpoint, and then increasing at the tail end of the vowel. As decreasing F2 correlates with lingual movement toward the posterior of the oral cavity, these vowels all tend to back slightly at the beginning but front in the middle and end. The main exception to this contour is the female Korean "O" in the post-coronal and pre-lateral context, which only slightly increases throughout its trajectory, while the male speakers' counterpart has the most striking parabolic shape of all. In

Table 3
Model comparison of base GAMM and test GAMM for OW/O and UW/U.

Vowel	Formant	Model	Score (AIC)	Edf	Difference	Df	*p*
OW, /o/	F2	Base	21321.13	37			
		Test	20801.84	67	519.281	30	<0.001***
UW, /u/	F2	Base	5552.437	37			
		Test	4603.679	67	948.759	30	<0.001***

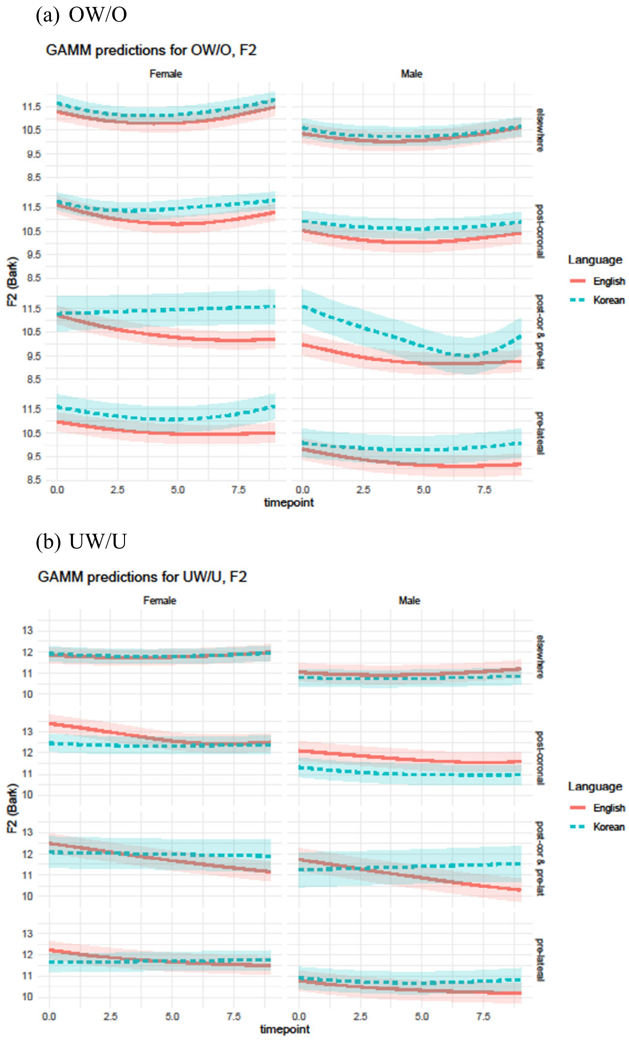

Fig. 4. Final Generalized Additive Mixed Model (GAMM) prediction of F2 trajectories of (a) English /oʊ/ and Korean /o/ (OW, O), and (b) English /u/ and Korean /u/ (UW, U), and their pre-lateral counterparts (OWL, OL, UWL, and UL), split by gender.

addition, according to these model predictions, the English "OW" consistently has a lower F2 in all contexts.

Table 4 summarizes the final model for OW/O. Most parametric terms and nearly all smooth terms were found to be significant, indicating true "wiggliness", or changes, in F2 contour. The main exceptions included the parametric term for female-Korean-elsewhere and female-Korean-pre-lateral "O", male-Korean-elsewhere and male-Korean-post-coronal "O", and several of the parametric effects that were crossed with log vowel duration.

A separate GAMM was run for the high back rounded vowels (UW/U) and their pre-lateral counterparts. The same modeling process was used, comparing a base model to a test model that included a smooth term for timepoint, crossed with gender, language, and pre-lateral context. Table 5 illustrates the results of the model comparison for UW/U. Overall, the results are the same as for OW/O.

The model's predictions for F2 of UW/U are visualized in Fig. 4b. Compared to OW/O, the contours for UW/U are generally less parabolic and more linear or level. For both male and female speakers, English /u/ is more diphthongized, having a consistent falling trajectory in post-coronal, pre-lateral, and post-coronal and pre-lateral environments. However, Korean /u/ in all contexts remains level throughout the entire vowel duration. Korean /u/ has a lower F2 than its English counterpart in the post-coronal context, but a coarticulatory effect draws English /u/ F2 downward throughout the trajectory of the vowel, which can be seen in the pre-lateral and post-coronal and pre-lateral contexts.

Table 5 summarizes the final model for UW/U. Like the OW/O model, most parametric coefficients were significant, except for three of the female Korean phonological context parametric terms, male-English-post-coronal terms, and male-Korean-pre-lateral terms.

4. Discussion

This study was conducted to determine the effect of language spoken on the back vowel formant contours of bilingual speakers of heritage Korean and English. It was predicted that heritage bilinguals would demonstrate different targets for their high back vowels of both languages. In addition, the influence of the California Vowel Shift was predicted to result in a higher F2 in English vowels except in the pre-lateral context but have no effect on Korean vowels.

The first hypothesis was that English and Korean /u/ would differ in F1 and F2. This hypothesis was partially correct. English /u/ was extremely fronted in the post-coronal context, backed in the pre-lateral context, and otherwise fairly central in the elsewhere context, while Korean /u/ showed a smaller effect of fronting and backing. The difference in coarticulation was most clearly seen for male speakers in the pre-lateral context, where English /u/ and Korean /u/ are at nearly opposite ends of the "back vowel" space. However, when looking at the elsewhere phonological context, it is clear that even the Korean /u/ is more central than back, which looks like the same effect that the California Vowel Shift has on English /u/. As mentioned previously, the fronted Korean /u/ could also be a consequence of the raising of Korean /o/, so the baseline frontedness of the Korean /u/ in the elsewhere context cannot be traced solely to influence from English. Overall, the Korean and English /u/ were similar enough in F2 across most contexts that the linear regression analysis did not show a significant difference between them.

The second hypothesis was that English /oʊ/ and Korean /o/ would also differ along F1 and F2. This hypothesis was mostly correct. The two vowels differed significantly in F1, with the Korean vowel higher than the English vowel. They also differed significantly in F2. Both were robustly back vowels with a similar F2 as English /ɑ/. However, for male speakers, there was a notable difference between English and Korean, particularly in the post-coronal and pre-lateral contexts: the extent to which Korean /o/ appeared to have a higher F2 than English /oʊ/ was driven mostly by both a lack of post-coronal fronting and a strong effect of pre-lateral backing for English /oʊ/, although it is also possible that the observed post-coronal fronting for Korean /o/ was increased due to the more anterior positioning of Korean coronal consonants.

The main contour for F2 for all vowels resembled a decrease in F2 prior to the vowel midpoint, followed by an increase in the latter half of the vowel. Given that even canon-

Table 4
Final GAMM summary for OW/O.

A. parametric coefficients	Estimate	Std. Error	*t*-value	*p*-value
(Intercept)	9.9806	0.1859	53.6895	**<0.0001**
Gender_lang_phontextFemale.English.PC	0.1608	0.0822	1.9564	**0.0504**
Gender_lang_phontextFemale.English.PCPL	−0.4151	0.2039	−2.0351	**0.0418**
Gender_lang_phontextFemale.English.PL	−0.6853	0.2703	−2.535	**0.0112**
Gender_lang_phontextFemale.Korean.OTHER	−0.0039	0.0959	−0.0405	0.9677
Gender_lang_phontextFemale.Korean.PC	0.3041	0.1532	1.9848	**0.0472**
Gender_lang_phontextFemale.Korean.PCPL	2.0541	0.9493	2.1637	**0.0305**
Gender_lang_phontextFemale.Korean.PL	0.3227	0.4156	0.7764	0.4375
Gender_lang_phontextMale.English.OTHER	−0.5364	0.272	−1.9716	**0.0487**
Gender_lang_phontextMale.English.PC	−0.6846	0.2731	−2.5069	**0.0122**
Gender_lang_phontextMale.English.PCPL	−1.9628	0.3697	−5.3095	**<0.0001**
Gender_lang_phontextMale.English.PL	−1.3737	0.3658	−3.7556	**0.0002**
Gender_lang_phontextMale.Korean.OTHER	−0.198	0.2769	−0.715	0.4746
Gender_lang_phontextMale.Korean.PC	0.1581	0.3138	0.5039	0.6143
Gender_lang_phontextMale.Korean.PCPL	−1.9214	0.5254	−3.6566	**0.0003**
Gender_lang_phontextMale.Korean.PL	−0.9993	0.4736	−2.1102	**0.0348**
duration_log	−0.4524	0.0232	−19.5016	**<0.0001**
Gender_lang_phontextFemale.English.PC:duration_log	0.0483	0.027	1.7911	0.0733
Gender_lang_phontextFemale.English.PCPL:duration_log	0.056	0.078	0.7187	0.4723
Gender_lang_phontextFemale.English.PL:duration_log	−0.111	0.1072	−1.0356	0.3004
Gender_lang_phontextFemale.Korean.OTHER:duration_log	−0.1442	0.0314	−4.5884	**<0.0001**
Gender_lang_phontextFemale.Korean.PC:duration_log	−0.0974	0.0534	−1.8261	0.0678
Gender_lang_phontextFemale.Korean.PCPL:duration_log	0.7143	0.3304	2.1621	**0.0306**
Gender_lang_phontextFemale.Korean.PL:duration_log	0.0209	0.1891	0.1104	0.9121
Gender_lang_phontextMale.English.OTHER:duration_log	0.1142	0.033	3.4592	**0.0005**
Gender_lang_phontextMale.English.PC:duration_log	0.0577	0.0282	2.0445	**0.0409**
Gender_lang_phontextMale.English.PCPL:duration_log	−0.1413	0.094	−1.5031	0.1328
Gender_lang_phontextMale.English.PL:duration_log	0.1477	0.0924	1.5979	0.1101
Gender_lang_phontextMale.Korean.OTHER:duration_log	0.1922	0.0317	6.0655	**<0.0001**
Gender_lang_phontextMale.Korean.PC:duration_log	0.1982	0.062	3.1943	**0.0014**
Gender_lang_phontextMale.Korean.PCPL:duration_log	−0.5364	0.1739	−3.0852	**0.002**
Gender_lang_phontextMale.Korean.PL:duration_log	0.0514	0.1571	0.327	0.7437
B. smooth terms	edf	Ref.df	F-value	p-value
s(tp):Gender_lang_phontextFemale.English.OTHER	6.9358	7.397	70.9317	**<0.0001**
s(tp):Gender_lang_phontextFemale.English.PC	7.1663	7.4895	94.7098	**<0.0001**
s(tp):Gender_lang_phontextFemale.English.PCPL	4.8935	6.0383	32.8985	**<0.0001**
s(tp):Gender_lang_phontextFemale.English.PL	3.6785	4.7219	8.9388	**<0.0001**
s(tp):Gender_lang_phontextFemale.Korean.OTHER	7.1701	7.5501	75.7083	**<0.0001**
s(tp):Gender_lang_phontextFemale.Korean.PC	6.4061	7.2411	22.1569	**<0.0001**
s(tp):Gender_lang_phontextFemale.Korean.PCPL	1.001	1.0019	1.2205	0.2691
s(tp):Gender_lang_phontextFemale.Korean.PL	3.964	5.1208	6.3248	**<0.0001**
s(tp):Gender_lang_phontextMale.English.OTHER	6.2297	6.9441	32.9581	**<0.0001**
s(tp):Gender_lang_phontextMale.English.PC	6.5376	7.0902	37.5887	**<0.0001**
s(tp):Gender_lang_phontextMale.English.PCPL	4.3054	5.4686	14.0221	**<0.0001**
s(tp):Gender_lang_phontextMale.English.PL	3.9517	5.0497	12.3096	**<0.0001**
s(tp):Gender_lang_phontextMale.Korean.OTHER	6.5777	7.2256	25.9656	**<0.0001**
s(tp):Gender_lang_phontextMale.Korean.PC	4.5449	5.6576	7.698	**<0.0001**
s(tp):Gender_lang_phontextMale.Korean.PCPL	5.2072	6.464	9.9288	**<0.0001**
s(tp):Gender_lang_phontextMale.Korean.PL	3.0993	4.0744	1.9676	0.0942
s(word)	833.9861	1064	5.0864	**<0.0001**
s(tp,Subject)	158.7433	189	217.12	**<0.0001**

ical monophthongs such as the English /ɑ/ showed a similar contour, I interpret this as an artifact of articulatory transitions in and out of a vowel and conclude that the English /oʊ/ was more monophthongized (rather than Korean /o/ being diphthongized).

The model comparison analysis demonstrated that language and phonological context were crucial for distinguishing between similar vowels across languages. Together, these results support the prediction that the population in question, heritage speakers of Korean who are dominant in English as adults, have maintained separate vowel systems for their two languages, with separate coarticulatory effects but apparent influence of an ongoing change in English seen in Korean in the elsewhere context.

The last hypothesis was that English vowels that occur adjacent to coarticulation-inducing segments such as syllable-final /l/ or syllable-initial coronal consonants would show different contours from other vowels, but that this effect would not be observed in Korean. This hypothesis was, again, mostly correct. The GAMM analysis corroborates the finding from the linear mixed effects regression analysis that the language being spoken significantly affects the formant values of the vowels, especially in the pre-lateral phonological context. Korean vowels tended to stay more level in F2 across the duration of the vowel (with the exception of post-coronal and pre-lateral /o/), while the contours of English vowels were more sloped. Furthermore, the GAMM analysis shows that the effect occurs not only at the midpoint of the vowel, but throughout its entire trajectory.

It is important to note, however, that the lateral consonant of each language in post-vocalic contexts may be articulatorily and acoustically different. A post-vocalic English /l/ may be "light" or "dark", generally tending towards "dark" in coda position, meaning a more posterior articulation using the tongue

Table 5
Final GAMM summary for UW/U.

A. parametric coefficients	Estimate	Std. Error	*t*-value	*p*-value
(Intercept)	11.4909	0.2077	55.3205	**<0.0001**
Gender_lang_phontextFemale.English.PC	0.7246	0.1896	3.8208	**0.0001**
Gender_lang_phontextFemale.English.PCPL	1.9352	0.3647	5.3062	**<0.0001**
Gender_lang_phontextFemale.English.PL	−0.7307	0.2162	−3.3796	**0.0007**
Gender_lang_phontextFemale.Korean.OTHER	−0.4706	0.1751	−2.6874	**0.0072**
Gender_lang_phontextFemale.Korean.PC	−0.5326	0.4672	−1.1399	0.2543
Gender_lang_phontextFemale.Korean.PCPL	1.5212	1.036	1.4684	0.142
Gender_lang_phontextFemale.Korean.PL	0.0481	0.4799	0.1002	0.9202
Gender_lang_phontextMale.English.OTHER	−1.5827	0.282	−5.613	**<0.0001**
Gender_lang_phontextMale.English.PC	0.2362	0.3174	0.7444	0.4566
Gender_lang_phontextMale.English.PCPL	−0.8252	0.4876	−1.6925	0.0906
Gender_lang_phontextMale.English.PL	−1.2525	0.3929	−3.1883	**0.0014**
Gender_lang_phontextMale.Korean.OTHER	−2.3197	0.3313	−7.0013	**<0.0001**
Gender_lang_phontextMale.Korean.PC	−2.5504	0.4738	−5.3826	**<0.0001**
Gender_lang_phontextMale.Korean.PCPL	−0.3636	0.8346	−0.4356	0.6631
Gender_lang_phontextMale.Korean.PL	−1.1229	0.7017	−1.6002	0.1096
duration_log	−0.1164	0.0316	−3.6894	**0.0002**
Gender_lang_phontextFemale.English.PC:duration_log	−0.0723	0.0383	−1.8898	0.0588
Gender_lang_phontextFemale.English.PCPL:duration_log	0.7084	0.1315	5.3886	**<0.0001**
Gender_lang_phontextFemale.English.PL:duration_log	−0.2332	0.0645	−3.6174	**0.0003**
Gender_lang_phontextFemale.Korean.OTHER:duration_log	−0.1771	0.0487	−3.6355	**0.0003**
Gender_lang_phontextFemale.Korean.PC:duration_log	−0.3866	0.1479	−2.6136	**0.009**
Gender_lang_phontextFemale.Korean.PCPL:duration_log	0.4804	0.3427	1.4017	0.161
Gender_lang_phontextFemale.Korean.PL:duration_log	0.0598	0.1429	0.4184	0.6757
Gender_lang_phontextMale.English.OTHER:duration_log	−0.2746	0.046	−5.9766	**<0.0001**
Gender_lang_phontextMale.English.PC:duration_log	0.1126	0.0417	2.6981	**0.007**
Gender_lang_phontextMale.English.PCPL:duration_log	0.0194	0.1639	0.1183	0.9058
Gender_lang_phontextMale.English.PL:duration_log	0.0646	0.0974	0.6628	0.5075
Gender_lang_phontextMale.Korean.OTHER:duration_log	−0.4546	0.0612	−7.4213	**<0.0001**
Gender_lang_phontextMale.Korean.PC:duration_log	−0.6299	0.1211	−5.2009	**<0.0001**
Gender_lang_phontextMale.Korean.PCPL:duration_log	0.0205	0.2338	0.0875	0.9303
Gender_lang_phontextMale.Korean.PL:duration_log	−0.0216	0.1954	−0.1106	0.9119
B. smooth terms	edf	Ref.df	F-value	p-value
s(tp):Gender_lang_phontextFemale.English.OTHER	4.7591	5.8613	12.5921	**<0.0001**
s(tp):Gender_lang_phontextFemale.English.PC	6.8052	7.5249	131.8621	**<0.0001**
s(tp):Gender_lang_phontextFemale.English.PCPL	2.4063	3.1706	69.3764	**<0.0001**
s(tp):Gender_lang_phontextFemale.English.PL	4.3025	5.445	39.2859	**<0.0001**
s(tp):Gender_lang_phontextFemale.Korean.OTHER	4.6882	5.7558	9.5887	**<0.0001**
s(tp):Gender_lang_phontextFemale.Korean.PC	2.6446	3.4916	1.4243	0.2562
s(tp):Gender_lang_phontextFemale.Korean.PCPL	1.0017	1.0035	0.5782	0.448
s(tp):Gender_lang_phontextFemale.Korean.PL	1.0018	1.0035	1.2868	0.256
s(tp):Gender_lang_phontextMale.English.OTHER	4.6134	5.7534	10.8703	**<0.0001**
s(tp):Gender_lang_phontextMale.English.PC	5.0567	6.1381	32.8433	**<0.0001**
s(tp):Gender_lang_phontextMale.English.PCPL	2.0332	2.6695	43.2141	**<0.0001**
s(tp):Gender_lang_phontextMale.English.PL	3.8716	4.9862	17.4716	**<0.0001**
s(tp):Gender_lang_phontextMale.Korean.OTHER	3.3636	4.2525	3.845	**0.0033**
s(tp):Gender_lang_phontextMale.Korean.PC	3.0625	4.0161	5.9771	**0.0001**
s(tp):Gender_lang_phontextMale.Korean.PCPL	1.0009	1.0019	1.6784	0.195
s(tp):Gender_lang_phontextMale.Korean.PL	2.9061	3.8399	2.2053	0.0686
s(word)	456.3321	528	9.9099	**<0.0001**
s(tp,Subject)	101.8977	188	226.9047	**<0.0001**

root and body, rather than its tip and blade (Sproat & Fujimura, 1993). The Korean /l/ in this same syllable coda position, in contrast, encompasses a large and variable articulatory space, including posterior, anterior, and even retroflex articulations (Hwang et al., 2019), although it never surfaces as its allophone /ɾ/ in this position. Coarticulation between the vowel and a posterior lateral consonant would account for the finding of F2-lowering effects in English, but the same phenomenon does not appear to occur in Korean. A detailed analysis of the F2 and F3 of the laterals themselves would be necessary to determine the articulatory identity of the post-vocalic laterals and their subsequent effects on vowel F2 with more certainty.

Additional deeper inquiry might examine other vowels implicated in the California Vowel Shift. It appears that the heritage bilinguals in this study, who grew up immersed in an environment where the California Vowel Shift is widely available, are producing an only moderately-fronted /oʊ/, whereas it is quite clear that their /u/ is characteristic of a fronted, centralized California /u/. The importance of studying vowels in specific phonological contexts (i.e., non-pre-lateral) is underscored by the stark differences in F2 reported when comparing /oʊ/ and /u/ to their pre-lateral counterparts. The logical next step would be to examine the front vowels, such as the pre-nasal split identified in the low front unrounded vowel /æ/ or the retraction of all front lax vowels (though see Kim & Wong (2020) for a recent analysis).

5. Conclusion

Overall, for the bilingual heritage speakers in this study, there was no “merged system” of back round vowels: the language being spoken significantly affects the realization of F1 and F2 in their vowels. In the OW/O comparison, the English vowels tended to have lower F2 than the Korean vowels, and the effect of a syllable-final /l/ on English vowels is a strong lowering in F2, but there is no corresponding effect on Korean vowels. In the UW/U comparison, the English vowels tended to have slightly higher F2 than the Korean vowels, except when taking the influence of post-vocalic /l/ into account.

A past study of Korean and English vowels of two monolingual groups found higher F1 and F2 in English /oʊ/ than Korean /o/, and higher F2 in English /u/ than Korean /u/ (Yang, 1996). The present study of heritage bilinguals mostly found the same (arguably) intrinsic vowel quality patterns as Yang (1996), although the lower F2 for English /oʊ/ in this data could be explained in part by the effects of coarticulation in English. The Baker and Trofimovich (2005) study of bilinguals concluded that early versus late Korean-English bilinguals differed in their production of Korean and English vowels. In this study, I found that simultaneous heritage bilinguals of Korean and English produce different vowels for each language, patterning more similarly with the early sequential bilinguals in Baker and Trofimovich (2005).

This study demonstrates that heritage bilinguals in the United States context, who grow up with one language but then are immersed in and switch in dominance to the majority language in society, have multicompetence in English and Korean. They can maintain phonetic and phonological distance in the back vowel contours of both vowel systems. Their heritage language phonology does not simply conform to the patterns in their dominant language, as has been seen in early sequential bilinguals. But neither do they match the disproven stereotype of being “two monolinguals in one”. In this way, we find that on the level of phonetics and phonology, heritage speakers do strongly resemble “balanced” bilinguals who have a shared phonological system.

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Statement of ethics

The procedures for recruitment, consent, data collection, and data analysis described in this section were approved by the Institutional Review Board of the University of California, Berkeley on March 18, 2016 (ID: 2016-01-8238; PI: Keith Johnson), and all study personnel completed the ethical training required by the Collaborative Institutional Training Initiative Program. All participants gave their written informed consent to participate in the study.

Conflict of interest statement

The author has no conflicts of interest to declare.

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