Cross-linguistic f0 differences in bilingual speakers of English and Korean*

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Abstract: Languages may differ in fundamental frequency of voicing (f0), even when they are spoken by a bilingual individual. However, little is known in bilingual/L2 acquisition research about simultaneous bilinguals. With the expectation that speakers who acquired two languages early use f0 differently for each language, this study measured f0 in English–Korean early bilinguals' natural speech. The f0 level was higher for Korean than English, regardless of gender, age, or generational status (early and late bilinguals did not differ). The f0 span showed a language-gender interaction: males' span was larger in Korean, while females' span was larger in English. This study demonstrates that languages differ in f0 independent of speaker anatomy and suggests that children may acquire these differences in early childhood.

* *The Journal of the Acoustical Society of America* **147**, EL67 (2020);
https://doi.org/10.1121/10.0000498

1. Introduction

Studies show that some languages fundamentally differ in average vocal f0 measurements, even when speaker differences are accounted for. Some common measurements include f0 level, which is similar to sustained average f0, and f0 span, which is the range between the high and low ends of a speaker's f0 range. For example, Mennen *et al.* (2012) compared female speakers of German and English and found that the English speakers had higher f0 level and wider f0 span. Both English and German were found to have lower f0 levels and narrower spans than either of two Slavic languages (Bulgarian and Polish), analyzed in Andreeva *et al.* (2014).

However, in a comparison of English and Mandarin, Keating and Kuo (2012) found virtually similar f0 ranges for both groups of speakers, while other aspects of the f0 profile (including maximum, minimum, range, standard deviation, and multiple means) differed only insubstantially. Keating and Kuo do suggest that "a combination of linguistic and cultural differences" may influence cross-linguistic f0 differences.

The studies cited above offer evidence that vocal f0 can be a linguistic identity marker for individuals and groups (see Eckert (2008)) by comparing similar populations of monolingual speakers. However, a more sensitive measure might emerge from an investigation of how bilingual speakers produce their two languages. Bilingual speech controls for speaker-inherent differences (i.e., neutralizing the effect of anatomical differences on fundamental frequency) and places the languages in contrast with one another in the experience of the speaker. For example, Altenberg and Ferrand (2006) found that Russian-English bilingual women spoke Russian with a higher mean f0 than English, but Cantonese-English bilingual women showed no significant difference between languages, and all three groups were comparable across languages.

Another early study, Ohara (1999), found a difference between languages for bilingual Japanese-English speakers, but specifically for women, not men, and attributed the difference to gender performance. These studies only looked at one f0 measurement, essentially treating f0 as one-dimensional. More recent studies have improved on this by looking at more than just f0 level.

For example, Graham (2014) took a second look at Japanese-English bilinguals, analyzing five men and five women. This study measured f0 at relevant points in a standard

Japanese or English utterance, given the known patterns of each language's intonational prosody, and found statistically significant cross-language differences: Japanese has higher level and wider span than English. This partially corroborates Ohara (1999), but finds the same result for women and men, negating the gender socialization hypothesis. Graham still concludes that both sociophonetic and phonological factors (for f0 span) must be at play here, allowing that bilingual speakers of different genders may speak their languages differently. Indeed, a recent study of bilingual range, Ordin and Mennen (2017), found that female speakers of Welsh and English had systematically wider f0 ranges in Welsh compared to English, although male speakers showed no regular patterning.

Finally, Lee and Van Lancker Sidtis (2017) examined Mandarin-English and Korean-English bilingual speakers performing a variety of speech tasks: reading a passage, describing pictures, and giving a spontaneous monologue. They found higher f0 level in Korean compared to English across all tasks, and higher f0 variability in Korean compared to English in the monologue. This study's participants were all female speakers (mean age: 25 years) who had immigrated from South Korea to the United States at variable times (mean age of arrival: 13±7 years) and had been living in the United States for an average of 10.5 years (±4). This means that in terms of bilingual acquisition, the participants were most likely all sequential bilinguals, or speakers who had fully acquired proficient Korean prior to immersion in an English-dominant environment.

Simultaneous bilinguals are speakers who acquire two languages at approximately the same time, either from birth or prior to the age of 3 (Paradis, 2007). For many second generation Korean Americans, their language input from early childhood onward is a mix of Korean and English, and they come to be proficient in both languages natively, rather than being a native speaker of one language and then acquiring another. A comparison of sequential bilinguals to simultaneous bilinguals would reveal whether the kind of early childhood input given to simultaneous bilinguals affects their use of vocal f0 in a way that the input of speakers who acquire one language much later than the other does not. Studies have shown the effects of age of acquisition on L1 and L2 vowel production (Baker and Trofimovich, 2005) and native-like consonant VOT or development of separate phonological categories for consonants (Kang and Guion, 2006; Lee and Iverson, 2012), for example.

The current study tests vocal fundamental frequency (f0) level and span of both languages of English-Korean bilingual speakers. [1] Building on the findings of Lee and Van Lancker Sidtis (2017), the expectation is that the two languages will differ in the direction of Korean having higher level and wider span, even when speakers are engaging in natural conversational speech, instead of participating in facilitated speech tasks. In addition, the subject of study includes simultaneous bilinguals and sequential bilinguals in order to test whether age of acquisition (early versus late) affects f0 differentiation.

2. Methods

2.1 Sociolinguistic interview

Subjects recruited for the study participated in a bilingual sociolinguistic interview. The structure of the bilingual interview was as follows: interviewees were asked to give a short self introduction in Korean, which was followed by a casual interview conducted in Korean, centered on the interviewee's family, life, and hobbies. Then, the interviewee was asked to read several sentences in written Korean (designed for an accompanying study). Next, the interviewee silently read and signed some documents written in English, which served as a buffer between interview sections and languages. Finally, the interviewer began a second interview conducted in English, centered on the interviewee's opinions and experiences regarding Korean language, culture, and identity.

The Korean portion of the interview generally lasted from 5-15 minutes. The Korean reading sections generally lasted about 5 minutes, but were excluded from the present analysis, so as to only compare spontaneous speech in both languages. The English portion of the interview lasted from 20-45 minutes. Total interview time was one hour. Interviewees were not prohibited from code-switching, so interviewees sometimes uttered English words during the Korean portion, and vice versa.

2.2 Subjects

The results from fifteen interviewees are reported. They all identified as Korean American. Ten identified as cisgender female, and five as cisgender male. The age range was 18-29 years old (mean age: 21.1±3.1).

The Korean American community has a means of identifying members by their relationship to immigration, since many Korean American families immigrated to the United States in the past few decades. A "first generation" immigrant would be a Korean national

Table 1. Fifteen interviewees' demographic information.

Gender	Second generation	1.5 generation
Female	n=5 (born in USA; AOA=0)	n=4 (born in Seoul; AOA=3, 8, 10, 10)
		n=1 (born in Busan; AOA=5)
Male	n=3 (born in USA; AOA=0)	n=2 (born in Seoul; AOA=9, 10)
Sum	mean age=21.75±3.3	mean age=20.3±2.8; mean AOA 7.8±2.8

who immigrated to the United States as an adult and became a naturalized citizen; "second generation" Korean Americans are their children, born and raised in the United States. In addition, "1.5 generation" Korean Americans were born in Korea but immigrated with their families to the United States at a young age (Park, 1999). Of the fifteen subjects, eight identified as second generation (mean age: 21.75±3.3 years), and seven as 1.5 generation (mean age: 20.3±2.8 years; mean age of arrival: 7.8±2.8 years). All of the 1.5 generation interviewees were born in Seoul or the Seoul metropolitan area, with the exception of one interviewee, a female, who was born in Busan. Every interviewee had at least one parent who was born and raised in Seoul. Basic demographic information about the fifteen interviewees is provided in Table 1.

All the interviewees involved in this study were able to speak proficient conversational Korean. Two independent raters were asked to score a sample of speech from each subject's Korean interview on two 5-point Likert Scales for strength of accent in Korean and level of proficiency in Korean. Only the speakers who scored at a 3 or above on both scales were included in the analysis[2].

In terms of language acquisition, all of the 1.5 generation interviewees reported learning Korean first, then acquiring English upon immigrating to the United States. Thus, they could also be characterized as early sequential bilinguals. (Note, however, that most Korean children are exposed to minimal English even in South Korea, as it is a compulsory subject in the country's public education system.) Second generation interviewees were simultaneous bilinguals, as most reported learning Korean at home as their first language, then acquiring English either at home, in their neighborhoods, or at school once they reached schooling age. Two subjects reported English as their first language, and only one reported using only

English at home; all other interviewees reported use of only Korean or a mix of Korean and English with their family (i.e., parents or caregivers).

Overall, the crucial difference between this population and the population studied in Lee and Van Lancker Sidtis (2017) is that the current study's subjects acquired English at a much earlier age on average, and can be split into two categories of bilingual acquisition: simultaneous bilingualism (all of the second generation interviewees) or early sequential bilingualism (the 1.5 generation interviewees).

2.3 Interview transcription and data analysis

The interviewers were a team of four trained undergraduate research assistants, as well as the author, who are all fluent in Korean. Two of the RAs are Korean American (one 1.5 generation, one second generation); the other two, and the author, are of Asian descent, but not Korean. The phonetic data from the interviewers' speech was also recorded during the interviews, but has not been analyzed.

The interviews all took place in a specially outfitted laboratory at the University of California that is designed to resemble a living room, to ensure interviewee comfort and minimize some effects of "laboratory speech", while also contributing to "stylistic diversity" in speech research, as in Wagner *et al.* (2015). Interviewers and interviewees wore lapel microphones, and their speech was digitally recorded onto a computer.

Interviewers transcribed the speech by hand after each interview, and the transcriptions were then force-aligned to the audio recording using two modified versions of the Penn Forced Aligner (Yuan and Liberman, 2008), one for English and one for Korean. Formant and f0 data were extracted using the Inverse Filter Control method (Ueda *et al.*, 2007). F0 measurements taken every five milliseconds were averaged across the duration of each vowel. Then, average f0 was calculated per word, based on the average f0 of the stressed vowel of an English word, and the average f0 of every vowel of a Korean word. This is what is referred to in Mennen *et al.* (2012) as f0 level. Then, all Hertz measurements were converted to semitones with a base of 100 Hz, using the formula (log x - log 100)/log $2^{(1/12)}$, and coded in the statistical analysis as "f0_wd_st".

To determine f0 span, or the extent to which the high and low ends of an individual's f0 range are differentiated, the coefficient of variance (ratio of standard deviation to mean f0 in Hertz, then converted to semitones) as well as four range measurements were calculated.

The first range was the interquartile range (IQR) of each subject's f0. Using the IQR function in the dplyr package of R, the difference between the upper quartile and the lower quartile was calculated, giving the spread of the middle fifty percent of the f0 measurements per speaker (hence, coding as "rg50"). Then, using percentile calculation functions, the middle eighty percent, the middle ninety percent, and the middle ninety-eight percent ranges were calculated ("rg80", "rg90", "rg98"). Each range calculation encompasses a greater proportion of the f0 data. A greater value for any of these ranges indicates a wider f0 span, and a lower value indicates a narrower f0 span.

3. Results

3.1 Mean f0

Figure 1 demonstrates the results for one interviewee, Subject 20. It is clear that while f0 varies widely over the duration of the interview, the Korean and English sections of the interview also differ. The orange dots, representing f0 measurements from Korean words, cluster at a higher f0 value in semitones, compared to the green dots, which represent f0 measurements from English words. (Code-switched words, such as English words occuring during the Korean interview, were excluded from analysis.)

This pattern, which is evident in one subject, also held when all the interviewees were pooled by gender. Figure 2 illustrates overall f0 measurements from all interviewees, separated by gender and language. Despite considerable overlap, f0 measurements from Korean words were greater on average than f0 measurements from English words by up to five semitones.

To test for the significance of the observed difference, two linear mixed effects models were fit on the word-level f0 measurements and per-subject f0 means (in semitones), with fixed effects of gender, generation, and language spoken, and random effects for subject, according to the formula: f0_wd_st $\sim$ language * Gender + Generation + (1|subject). The results are illustrated in Table 2.

Results from the model show that the interviewees' Korean was significantly higher than their English, regardless of gender or generational status. There was no effect found for generation; that is to say, second generation and 1.5-generation Korean Americans did not behave differently in terms of f0. However, a small interaction between language and gender indicates that male and female speakers had somewhat different language effects.

Table 2. Two linear mixed effects models were fit on the data to determine the effects of language, speaker gender, and speaker generation on mean f0 of a particular word in semitones (f0_wd_st) and mean f0 per subject in semitones (f0_mean_sbj_st). One linear mixed effects model was fit on the data to determine the same effects on f0 variance (cv). The table displays coefficients, standard errors, and p-value indicators for each fixed effect.

	Dependent variable:		
	f0_wd_st	f0_mean_subj_st	cv
langKrn	2.333***	2.222***	−2.565***
	(0.019)	(0.329)	(0.702)
GenderM	-8.923***	−8.863***	1.322
	(1.433)	(1.264)	(2.393)
GenerationG2	0.759	0.285	−1.506
	(1.354)	(1.164)	(2.187)
langKrn:GenderM	−0.154***	0.881	4.030***
	(0.050)	(0.570)	(1.217)
Constant	8.296***	9.181***	−22.841***
	(1.067)	(0.931)	(1.758)
Observations	480,737	30	30
Log Likelihood	−1,459,200	−50.238	−67.658
Akaike Inf. Crit.	2,918,413	114.476	149.316
Bayesian Inf. Crit.	2,918,491	124.285	159.125

Note: *p<0.1; **p<0.05; ***p<0.01

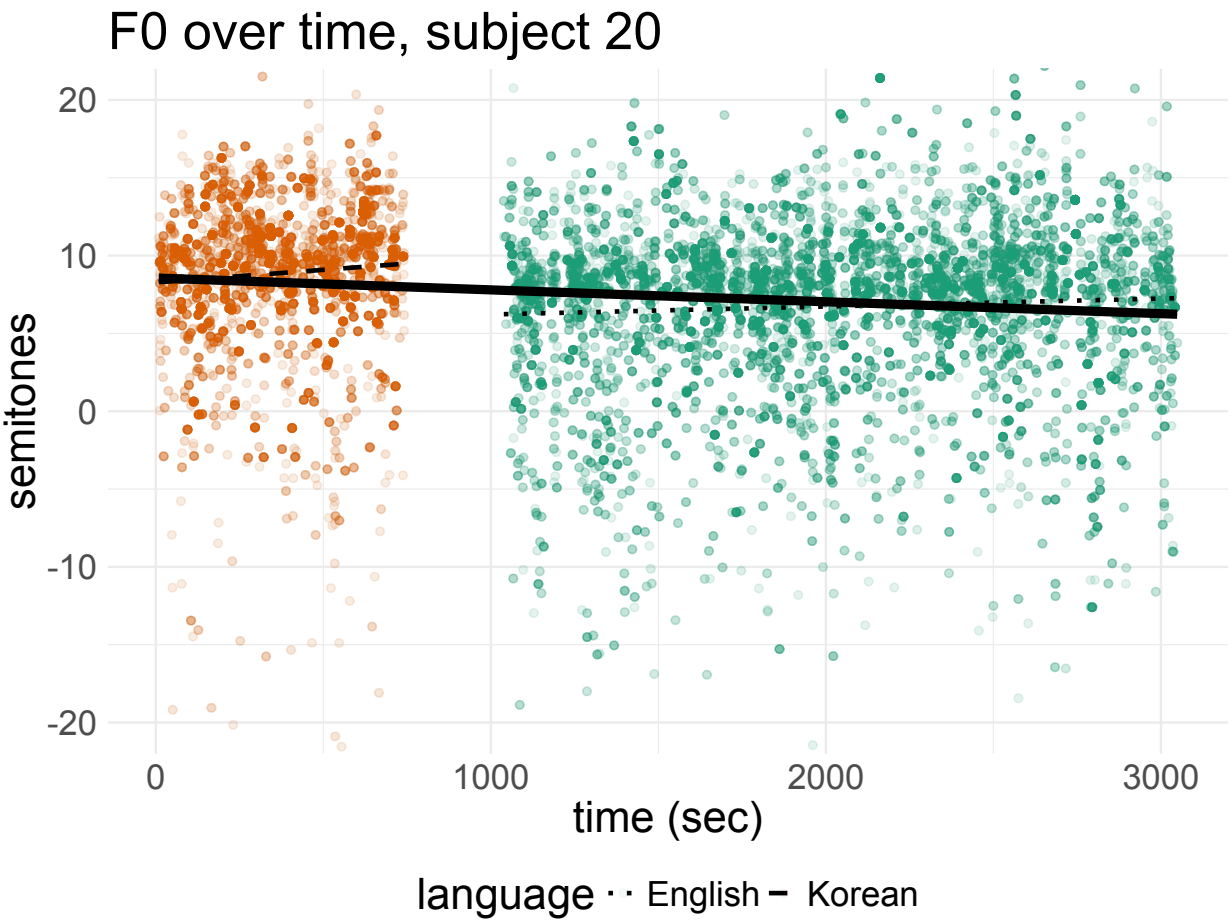

Fig. 1. Each dot represents the f0 of a vowel during the bilingual interview, with Korean speech (on the left) occurring first, followed by English speech (on the right), after a short period of silence. The regression lines were calculated for each language separately (dashed, dotted) as well as pooled (solid), using lm smoothing in R. This figure represents one subject, a 19-year-old second generation female.

3.2 F0 variance

As for f0 span, the hypothesis was that in these bilingual speakers, Korean speech would have a wider span, indicated by greater variance. Figure 3 shows the coefficient of variance for gender groups, by language. As with f0 mean, the two generational groups did not differ, so the two groups are pooled for the visualization. Variance was greater in Korean than in English for the male speakers, but lower in Korean than in English for the female speakers.

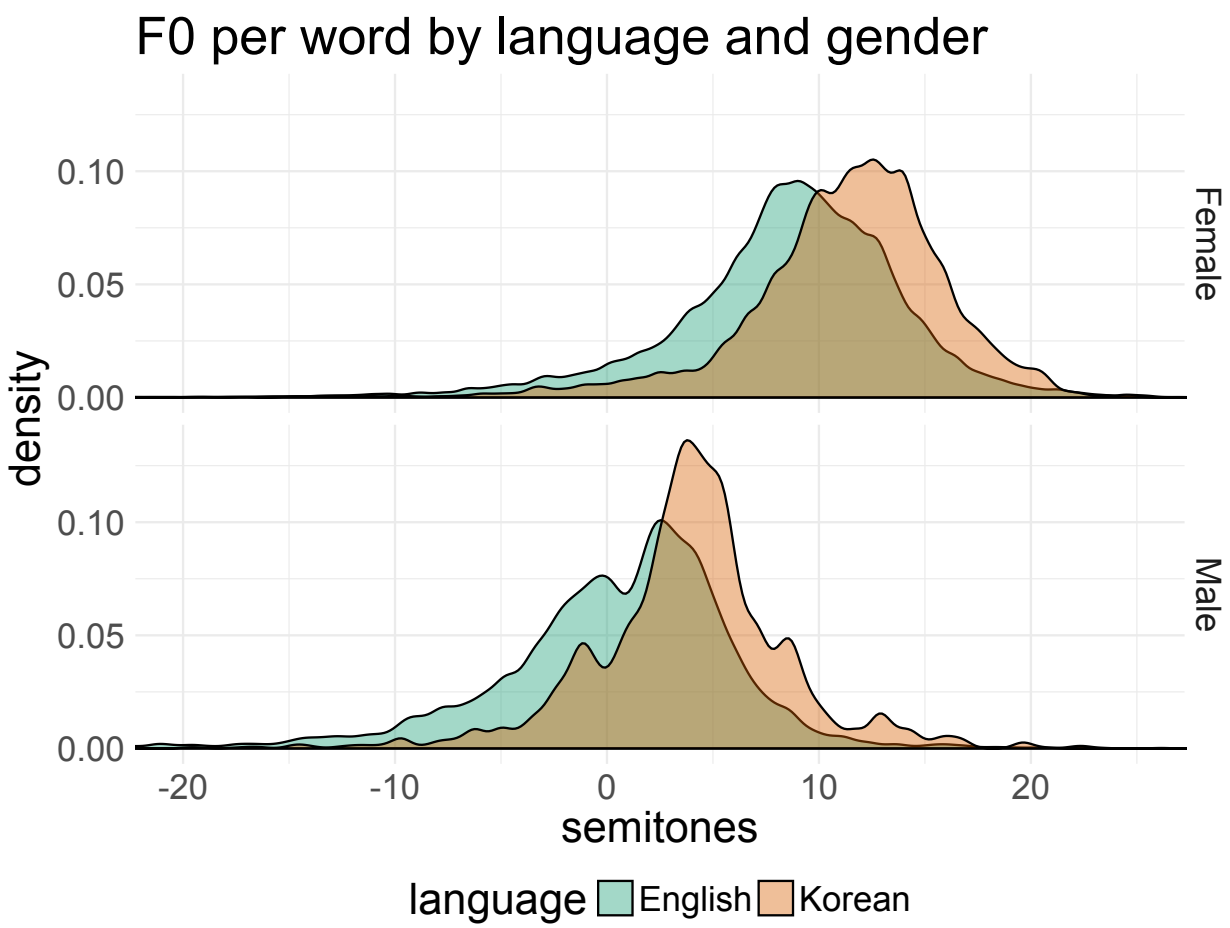

Fig. 2. Distribution plots of f0 measurements for all interviewees, separated by gender and language. On average, male-identified interviewees had lower f0, and English f0 measurements were lower than Korean f0 measurements.

To test for the significance of the observed difference, a linear mixed effects model was fit on the word-level f0 variance measurements ("cv"), with fixed effects of gender, generation, and language spoken, and random effects for subject, according to the formula: cv $\sim$ language * Gender + Generation + (1|subject). The results are illustrated in Table 2.

Results from the model show that interviewees' f0 variance did not significantly differ depending on the language being spoken alone, but on the language as well as speaker gender.

3.3 Interquartile Range (IQR) and other ranges

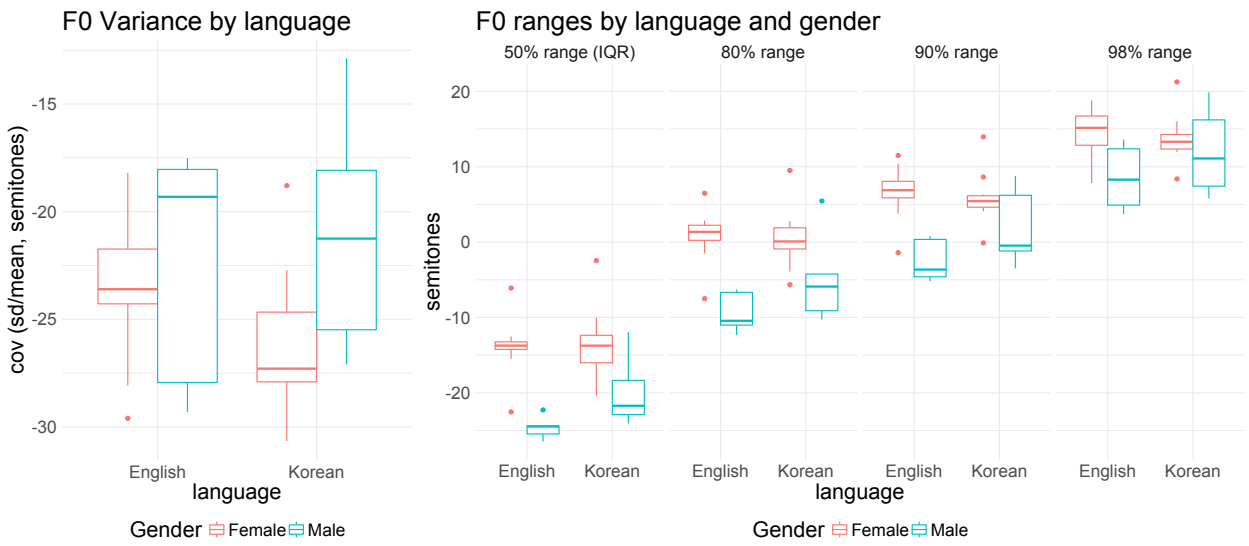

Fig. 3. Means and distributions of f0 variance (coefficient of variance) for gender and language (left) and f0 range (IQR, 80%, 90%, and 98% range) for gender and language (right). No effect of was found for gender or generation, but an interaction effect was found with gender and language.

Wider span is also indicated by higher values for ranges such as interquartile range. Figure 3 illustrates the data organized by language, gender, and range type. As with f0 mean and variance, the two generational groups did not differ, so that is not plotted. It is clear that male ranges are lower than female ranges in general. In addition, there is a visible interaction effect with language. While male speakers had larger ranges in Korean and smaller ranges in English, female speakers had slightly smaller ranges in Korean compared to English.

A linear mixed effects model was fit for each of the ranges in order to test for the effects of language, generation, and gender on f0 span, according to the formula: rg(50,80,90,98) ~ language * Gender + Generation + (1|subject). The results are illustrated in Table 3.

Results from the model show that interviewees' f0 span did not significantly differ depending on the language being spoken. Speakers' generational status was also not a factor. Speaker gender was found to be significant – male speakers had a narrower f0 span than female speakers – but more importantly, the interaction effect of language and gender was confirmed. Figure 4 demonstrates this by showing each of the nineteen subjects individually, ordered by female speakers first, followed by male speakers. From the English ranges to the

Table 3. A linear mixed effects model was fit on the data to determine the effects of language, speaker gender, and speaker generation on f0 IQR, 80% range, 90% range, and 98% range per subject, in semitones.

	Dependent variable:			
	rg50 (IQR)	rg80	rg90	rg98
langKrn	0.598	−0.365	−0.615	−0.813
	(1.321)	(1.343)	(1.012)	(0.862)
GenderM	−10.647***	−9.953***	−8.837***	−5.921***
	(2.350)	(2.289)	(2.107)	(2.274)
GenerationG2	−0.536	−1.853	−1.374	−0.502
	(1.939)	(1.863)	(1.810)	(2.029)
langKrn:GenderM	4.226*	4.905**	5.039***	4.312***
	(2.287)	(2.325)	(1.752)	(1.493)
Constant	−13.638***	1.718	7.210***	14.809***
	(1.664)	(1.613)	(1.513)	(1.655)
Observations	30	30	30	30
Log Likelihood	−74.420	−74.155	−70.132	−69.414
Akaike Inf. Crit.	162.840	162.309	154.263	152.827
Bayesian Inf. Crit.	172.648	172.118	164.072	162.636

Note: *p<0.1; **p<0.05; ***p<0.01

Korean ranges, most of the female speakers have a decrease in range or remain level, whereas most of the male speakers have an increase in range.

4. Discussion and Conclusion

The hypothesis that in bilingual speakers, Korean speech would have a higher f0 level was demonstrated to be correct. However, the hypothesis that Korean speech would also have a wider f0 span was not supported; instead, whether Korean had a wider f0 span depended on speaker gender.

Although the difference is basic and significant, the present data cannot tell us what the cause of the difference is, and one can only speculate. There are four hypotheses that warrant further investigation.

4.1 Discussion

First, it could be that the difference is purely phonetic: due to differences in the phonetic inventories of English and Korean. For example, the fortis and aspirated consonants in Korean are known to raise the f0 of subsequent vowels, in comparison to lenis consonants (and onset-less vowels). As suggested in Lee and Van Lancker Sidtis (2017), the regular occurrence and use of these kinds of consonants might push up the average Korean f0 in a way that English does not. This explanation would account for the finding that the middle fifty percent of the f0 measurements for both languages do not significantly differ. However, this f0 raising effect only occurs at the beginnings of accentual phrases (Cho and Jun, 2000), and fortis and aspirated consonants are not common consonants to begin with. The relative rarity of this f0 raising phenomenon in casual speech means that it is an unlikely contributor to the overall greater values for Korean f0.

Second, it could be that the suprasegmental phonological structure of Korean and English (i.e., prosodic structure) differs in a way that increases overall Korean f0 (or decreases English f0). This idea is supported by the studies of German and English (Mennen *et al.*, 2012) and Japanese and English (Graham, 2014) that specifically looked at f0 range at crucial intonational points of sentence-long utterances. Unfortunately, that level of specificity in the f0 analysis is beyond the scope of the current study (although the data would certainly be amenable to it).

Third, the difference could be socio-indexical. In light of the past socio-cultural and pragmatic studies of "pitch" (Loveday, 1981; Ohara, 1999), one could hypothesize that a

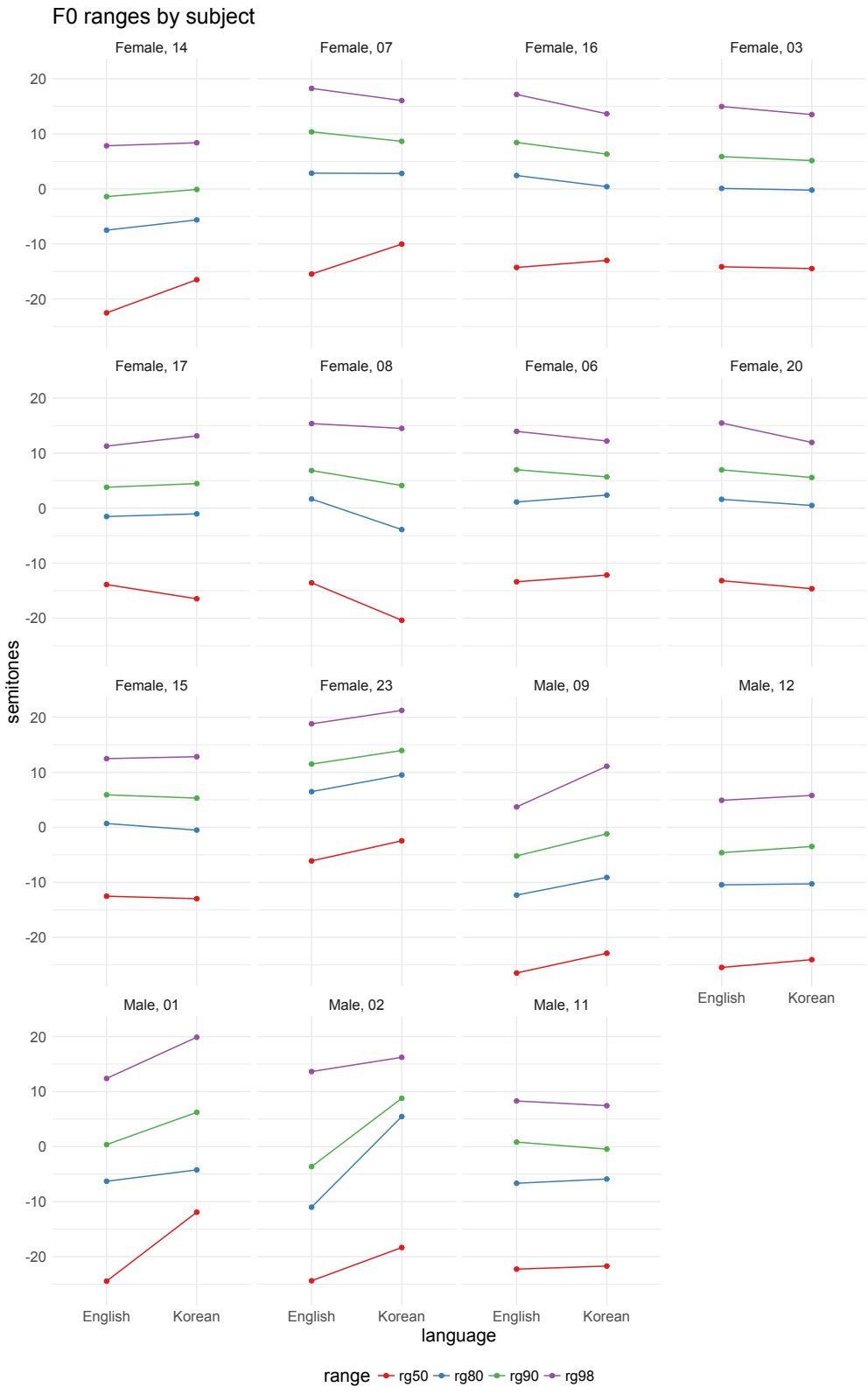

Fig. 4. Individual range measurements for each speaker: English on the left and Korean on the right, with a comparison line in between. The widest range (98%) is at the top, followed by 90%, 80%, and 50% (IQR). The general trend is for female speakers to have a smaller range in Korean, while male speakers have a larger range in Korean.

similar means of linguistic performance could be at work, whereby Korean Americans speak Korean with a higher f0 due to social expectations. It is unlikely that gender performance is the key factor here, however, since both male and female speakers in this study consistently spoke Korean with a higher f0. And unlike Loveday (1981), the speakers in this study were not restricted to conventional politeness expressions, but were engaging in uninterrupted natural conversation. Even in a study of acoustic correlates of Korean politeness (Brown *et al.*, 2014), the honorific expressions in Korean were found to have a lower average f0 than non-honorific ones. It is difficult to explain overall higher f0 in Korean with appeals to gender and politeness.

Finally, it is also unlikely that the influence of using a second language played a role. Although Lee and Van Lancker Sidtis (2017) discuss the idea that speaking a foreign language may raise f0, the speakers in the current study – including the 1.5 generation Korean Americans, but especially the second generation Korean Americans – acquired English at an early age and would not consider English to be a foreign or second language. Many of the speakers do consider Korean to be a heritage language or "home language", and some reported a lack of confidence in their Korean skills. But because they were childhood acquirers of the language, they cannot be considered L2 Korean learners, either. In the end, there were no significant effects of age of acquisition (or generational status) found in the f0 data, and neither did Korean proficiency appear to affect the observed phenomenon of higher f0 in Korean.

4.2 Methodological notes

One drawback of the data collection method is that the two portions of the interview were not counterbalanced (such that some interviews would begin in English and end in Korean). It is thus not possible to determine whether the order of languages in the interviews played a role in the results.

Many sociolinguistic interviews conducted in this manner analyze only the middle eighty percent of the duration of an interview, because the beginning of an interview may be affected by the interviewee's heightened awareness of being recorded (perhaps resulting in higher f0, or other effects of careful speech). The analysis of the current study included a test of whether time affected the f0 measurements, by adding time (using the start time,

in seconds, of each vowel) as a fixed effect into the linear mixed effects model, and found no significant effect.

It is plausible that because Korean was always the first language in an interview, the Korean f0 measurements were biased to be higher. However, there was no general decrease in f0 over time found in the data, so the original conclusion still holds.

Another potential drawback is that the study population did not include first generation bilingual Korean Americans (e.g., recent immigrants) who do not have the same associations as second and 1.5 generation Korean Americans when it comes to the Korean language. A future course of study would also include first generation or adult immigrant speakers with a complementary profile of language experience and proficiency, in order to compare the two.

In addition, it would be beneficial to collect speech data from non-Korean bilingual speakers of Korean and English (e.g., L1 English learners of Korean), once again to see if the same pattern holds. Similar to the first generation Korean Americans, if non-native bilingual speakers, who do not have the same culturally-mediated experience with Korean as second and 1.5 generation Korean Americans, demonstrate the same pattern as above, it would point more strongly toward purely linguistic (phonetic, phonological, and/or prosodic) explanations for the difference in f0 between Korean and English.

4.3 Conclusion

The present study has examined vocal f0 level and span in the natural speech of bilingual speakers of Korean and English and found a significant difference in f0 level. One can be sure that anatomical differences play no role in this robust cross-linguistic difference. F0 span was found to be dependent on speaker gender as well as language spoken. Finally, the study compared simultaneous bilinguals (second generation Korean Americans) to sequential bilinguals (1.5 generation Korean Americans) and found no significant difference between the two groups in f0 level and span.

With respect to other acoustic and phonetic research, the results of this study indicate that it is important to account for the effects of bilingualism (or a bilingual mode of speaking) when conducting research with natural speech. A bilingual speaker may have different average f0 values for each of the languages they speak, depending on what the languages are, or which language was spoken in childhood. (Most phonetic studies that are not about L2

acquisition is limited to "effectively" monolingual speakers, but many only ask for "native" speakers of the language in question, and should account for additional languages, if they do not already do so.)

Further research is recommended in the areas of examining cross-linguistic f0 differences at certain points in the prosodic structure of Korean and English utterances, as well as collecting natural speech data from the other bilingual populations mentioned in Section 4.1. Careful linguistic and ethnographic study is recommended in order to pinpoint some of the myriad possible socio-indexical influences, including the influence of heritage speaker status, on f0 in Korean and English, which may further inform our understanding of bilingualism as both a linguistic and cultural phenomenon.

References and links

[1]In this paper, I use f0 instead of "pitch", which refers to the perceptual dimension of frequency.

[2]I am grateful to an anonymous reviewer who noted that if early bilinguals experienced any language attrition and were no longer proficient in Korean but were aware of this, then a kind of stress that results from speaking a non-dominant language may have raised their f0 (Giddens *et al.* 2013). It remains possible that this phenomenon may have affected these speakers, as bilingual speakers who are more dominant in the ambient language of English. However, the study's findings still corroborate those found by Lee and Van Lancker Sidtis, whose subjects were a mix of early childhood bilinguals, late childhood immigrants, and adult immigrants.

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