

Interaction of Native- and Second-Language Vowel System(s) in Early and Late Bilinguals

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Key words

age

bilingualism

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Abstract

The objective of this study was to determine how bilinguals' age at the time of language acquisition influenced the organization of their phonetic system(s). The productions of six English and five Korean vowels by English and Korean monolinguals were compared to the productions of the same vowels by early and late Korean-English bilinguals varying in amount of exposure to their second language. Results indicated that bilinguals' age profoundly influenced both the degree and the direction of the interaction between the phonetic systems of their native (L1) and second (L2) languages. In particular, early bilinguals manifested a bidirectional L1-L2 influence and produced distinct acoustic realizations of L1 and L2 vowels. Late bilinguals, however, showed evidence of a unidirectional influence of the L1 on the L2 and produced L2 vowels that were "colored" by acoustic properties of their L1. The degree and direction of L1-L2 influences in early and late bilinguals appeared to depend on the degree of acoustic similarity between L1 and L2 vowels and the length of their exposure to the L2. Overall, the findings underscored the complex nature of the restructuring of the L1-L2 phonetic system(s) in bilinguals.

1 Introduction

How do bilinguals organize their phonetic system(s)? Does this organization depend on bilinguals' age at the time of second-language learning? By and large,

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two approaches have been employed to answer these questions addressing how age at the time of learning affects the phonetic system(s) of a bilingual's two languages. One approach is to compare bilinguals to monolinguals, or to carry out monolingual comparisons, in an attempt to determine the *direction* of native- (L1) and second-language (L2) influence (Flege, Schirru, & MacKay, 2003; Mack, 1989; MacKay, Flege, Piske, & Schirru, 2001). For example, one recent study comparing how Italian-English bilinguals and English monolinguals produced English vowels found that early bilinguals (Italians who learned English between ages 2 and 13), but not late bilinguals (Italians who learned English after the age of 15), produced English /eɪ/ in a less than native-like manner (articulating it with more tongue movement) when compared to monolingual English speakers (Flege et al., 2003). Apparently, the early bilinguals were attempting to overemphasize differences between English /eɪ/ and similar Italian vowels, suggesting that their L1 (Italian) influenced, or interacted with, their L2 (English).

Another approach to examining bilinguals' language organization is to compare bilinguals' L1 and L2—thus performing bilingual comparisons—to determine the *degree* or amount of L1-L2 influence (Flege, 1987; Flege, MacKay, & Piske, 2002; Guion, 2003; Mack, 1990). For example, another recent study determined that early (but not late) Quichua-Spanish bilinguals produced Quichua and Spanish vowels that did not overlap in acoustic properties, indicating that early bilinguals may organize their two languages as somewhat separate systems (Guion, 2003). In other words, the degree of L1-L2 influence was greater in late than in early bilinguals. In addition to suggesting that different approaches provide distinct perspectives on how bilinguals organize the phonetic system(s) in their two languages, these examples underscore the importance of individual differences, such as bilinguals' age at the time of learning, in determining how they do so.

Yet a third approach to studying bilingual language organization may be conceptualized as a combination of the first two—that is, as an examination of how bilinguals perceive and produce their two languages (bilingual comparison) *and* how similarly or differently they do so in comparison to monolinguals of both languages (monolingual comparison). Using the study of Quichua-Spanish bilinguals as a case in point (Guion, 2003), it would thus be revealing to determine how similar (or different) were the Quichua and Spanish vowels produced by early and late bilinguals to those produced by monolinguals. In other words, performing both types of comparisons may determine not only the direction of L1-L2 influence (e.g., greater L1-to-L2 than L2-to-L1 influence in late bilinguals) but also its degree (e.g., greater L1-L2 interaction in early than in late bilinguals).

Although comparisons of bilinguals to monolingual speakers of the bilinguals' L2 are not uncommon, only a handful of studies have compared bilinguals to monolingual speakers of the bilinguals' L1 to investigate the consequences that learning an L2 has upon an L1 (Bosch & Sebastián-Gallés, 2001, 2003; Mack, 1990; Mack, Bott, & Boronat, 1995). In addition, most of these studies have examined (nearly) simultaneous early bilinguals—those bilinguals who are exposed to an L2 at least by age 4 (and often earlier) instead of those who are exposed to their L2 later in life. Understanding how early and late bilinguals organize their phonetic system(s) in comparison to monolinguals of *both* L1 and L2 would shed light on the nature of

bilingual competence (e.g., Grosjean, 1985, 1989; Singh, 1998) and, more specifically, on bilingual language processing and learning (e.g., Costa, 2004).

Thus, the main objective of the present study was to determine—by carrying out both bilingual and monolingual comparisons—how early and late bilinguals organize and maintain their L1-L2 phonetic system(s) by examining both the direction and degree of L1-L2 influence. In addition to bilinguals' age (a variable of primary interest here), also investigated in the present study were two other variables known to affect the organization of phonetic system(s) in bilinguals and L2 learners—amount of experience and degree of cross-language similarity. These variables have received relatively little attention in studies comparing bilinguals to monolingual speakers of the bilinguals' L1, and have been investigated only in late, not in early, bilinguals.

The first of these variables is the amount of experience with the two languages. Late bilinguals may organize their two languages differently in the beginning and advanced stages of L2 learning. In particular, in the beginning stages of L2 learning, late bilinguals often perceive and produce at least some L2 vowels and consonants (“sounds”) as instances of L1 sounds (Best, 1995; Flege, 1995; Kuhl & Iverson, 1995). For example, native Korean speakers often perceive and produce English /ɪ/ as an instance of Korean /i/ (Baker, Trofimovich, Mack, & Flege, 2001; Trofimovich, Baker, & Mack, 2001). It is only after extensive exposure to an L2 that separate long-term memory representations (categories) for L2 sounds like English /ɪ/ are formed, if at all (Baker et al., 2001; Flege, Meador, & MacKay, 1999). Thus, in late bilinguals, L2 perception and production are often influenced by the L1 at least in the beginning stages of L2 learning. In later stages, the two languages may interact less so that late bilinguals' L2 is “colored” less by their L1.

Much less is known about how amount of experience influences the L1-L2 phonetic organization of early bilinguals. This is because most studies have examined early bilinguals only at advanced stages of L2 learning (e.g., Flege et al., 1999; MacKay et al., 2001). It is still largely unknown whether, in beginning stages of learning, early bilinguals perceive and produce their two languages in terms of a single, one-language system as late bilinguals presumably do (Best, 1995; Flege, 1995; Flege et al., 1999). It is certainly possible that they do not. The phonetic system(s) of early simultaneous bilinguals seems to be language-specific early in the learning process (e.g., Kehoe, 2002; Vihman, 2002), which may suggest that early bilinguals, just like children exposed to both languages from birth, may effectively “separate” their two languages at the onset of L2 learning. Surprisingly few studies have examined this question, especially on the phonetic level. One exception is the study by Aoyama, Flege, Guion, Yamada, and Akahane-Yamada (2003), who determined that early Japanese-English bilinguals who had recently begun learning English were able to improve over one year in the production of English /ɪ/ and /i/ significantly more so than late bilinguals with a similar amount of experience. That is, amount of L2 experience may play a less effective role in late than in early bilinguals' L2 phonetic learning.

Another variable that may determine how bilinguals organize their phonetic system(s) is the degree of similarity between L1 and L2 sounds, or cross-language similarity. In particular, the more similar L2 sounds are to L1 sounds perceptually, the more likely the L1 will influence how L2 sounds are perceived and produced (Best,

McRoberts, & Goodell, 2001; Flege, 1995). For example, Aoyama et al. (2003) determined that Japanese learners of English were more likely to perceptually differentiate English /ɪ/, but not /I/, from Japanese /ɪ/. These same Japanese learners produced English /ɪ/ more accurately than English /I/, suggesting perhaps that the ability to perceive cross-language differences between English /ɪ/ and Japanese /ɪ/ enabled the learners to produce English /ɪ/ more accurately than English /I/. That is, depending on cross-language similarity, bilinguals' L1 categories may influence how some L2 sounds are perceived and produced, thus determining how much the L1 and L2 interact in bilinguals (Baker et al., 2001; Guion, Flege, Akahane-Yamada, & Pruitt, 2000).

Again, it is less well known how cross-language similarity determines L1-L2 interaction in early bilinguals. It is possible that the L1 exerts less of an influence on early than on late bilinguals' L2 perception and production and, consequently, that cross-language similarity may play a less significant role in early than in late bilinguals (Baker et al., 2001). For example, early Italian-English bilinguals produce perceptually similar Italian and English voiced stops (/b, d, g/) with short-lag (English-like) voice-onset times (VOTs) whereas late bilinguals produce them with lead (Italian-like) VOTs (MacKay et al., 2001). Thus, late bilinguals may alter their L1 categories to accommodate similar L2 sounds whereas early bilinguals may do the opposite, creating merged L2-based categories to perceive and produce similar L1 and L2 sounds. Apparent in this example is a pattern of bidirectional L1-L2 influence that is different in early and in late bilinguals. Although revealing, such a pattern may hold true only for those L1 and L2 sounds that are highly similar perceptually—that is, the extent and direction of L1-L2 interaction may differ for sounds that are similar and dissimilar across bilinguals' two languages.

Whereas previous research has examined the *individual* effects of age, amount of experience, and cross-language similarity on the organization of bilinguals' L1 and L2, little research has investigated how these variables *combined* determine the degree and direction of L1-L2 influence and no study has employed monolingual comparisons to do so. Monolingual comparisons may indicate whether and how bilinguals' L1 sound categories change from their "initial" state (i.e., from age-matched L1 monolinguals' categories) and how bilinguals' L2 sound categories differ from their "end" state (i.e., from age-matched L2 monolinguals' categories) as an L2 is learned. Comparing monolingual productions of the sounds to each other may also indicate whether and how much sounds across the two languages overlap, providing an explanation for the acoustic overlap in bilingual language production (Mack et al., 1995). That is, there may be some sounds that are so similar across the L1 and L2, that it would be impossible for the bilinguals to "separate" them in perception or production. Such information is necessary, especially when examining bilinguals with varying degrees of L2 experience, in order to understand to what extent they are able to separate their two languages and process the L1 and L2 in a native-like manner.

Thus, the present study set out to examine the L1-L2 interaction in bilinguals by carrying out both bilingual and monolingual comparisons as described above. These comparisons determined both the degree and direction of L1-L2 interaction. In examining this interaction, the following two hypotheses were proposed: (1) the amount of similarity between L1 and L2 sounds would determine the degree and direction of

L1-L2 interaction in early and late bilinguals, and (2) the degree and direction of this interaction would be greater in the beginning than in advanced stages of L2 learning. These two hypotheses were investigated by comparing bilinguals and monolinguals in their production of L1 and L2 vowels. In particular, in the first experiment, English and Korean monolinguals were asked to produce six English and five Korean vowels, respectively. These productions were then compared to determine the degree of cross-language similarity (or “overlap”) between English and Korean vowels. In the second experiment, inexperienced early and late Korean-English bilinguals, as well as more experienced early and late Korean-English bilinguals, were asked to produce the same English and Korean vowels. These productions were then compared across the bilinguals’ two languages (bilingual comparisons) and to those of English and Korean monolinguals (monolingual comparisons).

2 Experiment 1: Korean and English monolinguals

The objective of this experiment was to determine the extent to which English and Korean vowels, as spoken by child and adult English and Korean monolinguals, overlap in the phonetic space. To accomplish this objective, English and Korean monolinguals were asked to produce six English and five Korean vowels, respectively. The English and Korean vowels used in this study were chosen because, in earlier studies, they were shown to represent a number of different cross-language perceptual relationships—from highly similar to relatively dissimilar perceptually (Baker et al., 2001; Trofimovich et al., 2001). Next, these English and Korean vowels were acoustically analyzed to examine the degree of cross-language similarity between them. Based on these findings, predictions of how bilinguals would organize their phonetic system(s) were made. The obtained monolinguals’ productions were later compared to the bilinguals’ productions in Experiment 2.

2.1

Participants

The participants were 20 Korean and 20 English monolinguals of which half were children and half were adults.

2.1.1

Korean monolinguals

The Korean children and adults (hereafter, the “K Child” and the “K Adult” groups, respectively) were functionally monolingual, although they had resided in the U.S. for a brief period. All, with the exception of two, were native speakers of the Seoul dialect of Korean. The participants in the K Child group were on average 11.7 years old (7–12 years) and those in the K Adult group were on average 31.9 years old (26–47 years). To restrict the amount of exposure to English in the U.S. to a minimum, only participants who had resided in the U.S. for less than eight months and had attended a school for less than two months were included. The Korean monolinguals were asked to rate their ability to speak, read, write, and comprehend English and Korean and to estimate the amount of Korean spoken daily. They rated their English on average a 2.7 (1–4) on a 10-point scale (1 = “I don’t speak any English,” 10 = “I am a

native English speaker”); they rated their Korean on average a 9.9 on the same scale and estimated that they had used Korean 71% (50–100%) of the time daily. These participants could not carry out even a simple conversation in English; therefore, all testing was conducted in Korean by a native Korean speaker.

2.1.2

English monolinguals

The English children and adults (hereafter, the “E Child” and the “E Adult” groups, respectively) were all native speakers of American English. None had lived in a foreign country where a language besides English was spoken, and none had studied a foreign language beyond high school and college courses. All participants were raised in monolingual English homes. The participants in the E Child group were on average 10.6 years of age (8–13 years) and those in the E Adult group were on average 20.7 years of age (18–25 years). Although the English monolingual adults ($M = 20.7$ years) were younger than the Korean monolingual adults ($M = 31.9$ years), it was assumed that these English and Korean adults’ respective L1 vowel systems were “stable” and that a 10-year difference in young adults’ age would not compromise their being representative native speakers of their respective languages. This assumption was supported by findings of previous studies that have yielded differences in L1 speech processing only between groups of younger and older (aged 55 and older) adults (e.g., Bellis, Nicol, & Kraus, 2000). (See Table 1 for a summary of pertinent information about the participants.)

TABLE 1

Means and *SDs* (in parentheses) for participant variables in Experiment 1

| <i>Group</i> | <i>Age^a</i> | <i>AOA^b</i> | <i>LOR^c</i> | <i>K. Use^d</i> | <i>K. Rate^e</i> | <i>E. Rate^f</i> |
|------------------|------------------------|------------------------|------------------------|---------------------------|----------------------------|----------------------------|
| K Child (n = 10) | 11.7 (2.5) | 11.1 (2.5) | 0.6 (0.1) | 58% | 9.8 (0.6) | 3.1 (0.6) |
| K Adult (n = 10) | 31.9 (8.2) | 31.3 (7.9) | 0.6 (0.1) | 84% | 10.0 (0.0) | 2.3 (1.2) |
| E Child (n = 10) | 10.6 (2.6) | | | | | 10.0 (0.0) |
| E Adult (n = 10) | 20.7 (1.7) | | | | | 10.0 (0.0) |

^aAge at the time of testing, in years. ^bAge of arrival in the U.S., in years. ^cLength of U.S. residence, in years. ^dPercent of daily Korean use. ^eKorean self-rating from 1 to 10. ^fEnglish self-rating from 1 to 10.

2.2

Stimuli

The stimuli used in this experiment consisted of six English vowels (/i/, /ɪ/, /æ/, /ɛ/, /u/, /ʊ/) in 18 CVC monosyllabic words and five Korean vowels (/i/, /ɛ/, /e/, /u/, /ɨ/) in 10 disyllabic words (Table 2). The words used in this study were chosen because they represented picturable concrete objects suitable for a picture-naming task (described in detail below). In order to have picturable words that differed only in the vowel, monosyllabic English words were chosen. It was impossible, however, to find mono-

syllabic Korean words that had the same characteristics. Thus, the chosen Korean words were disyllabic but were matched to the chosen English words as closely as possible in their phonotactics, such that the syllable in which the vowel was placed contained either a voiced/voiceless stop or a voiceless glottal fricative. This difference in syllable length across the word sets in the two languages was not seen to be a limitation in comparing vowel quality in English and Korean (see Yang, 1996, for an example of English and Korean vowel comparisons using monosyllabic English and disyllabic Korean word stimuli).

Words containing four other English and Korean vowels, English /a/ and /ʌ/ and Korean /a/ and /ʌ/, were also initially included in this experiment. These data, although analyzed, were not included in the final dataset because the Korean words eliciting these vowels were largely unfamiliar to the children. For example, the children had difficulty remembering the (low-frequency) word ‘hakgan’ (*barn*) and producing it accurately. Because the Korean children did not reach a 90% production-accuracy criterion in their naming of pictures eliciting the Korean /a/ and /ʌ/, the sample of these vowels was not deemed representative and thus did not allow for valid comparisons of English and Korean children’s and adults’ production of English /a/ and /ʌ/ and Korean /a/ and /ʌ/, respectively.

TABLE 2

English and Korean stimuli

| <i>English</i> | | | | | |
|-------------------------|-----------------------------|-------------------------|----------------------|------------------------------|------------|
| <i>/i/</i> | <i>/u/</i> | <i>/æ/</i> | <i>/ɛ/</i> | <i>/ʊ/</i> | <i>/ɪ/</i> |
| beat | boot | bat | pet | book | bit |
| bead | booted | bad | bed | good | big |
| heat | hoop | had | head | hood | hid |
| <i>Korean</i> | | | | | |
| <i>/i/</i> | <i>/u/</i> | <i>/ɛ/</i> | <i>/ɛ/</i> | <i>/i/</i> | |
| bihang <i>flying</i> | bukchae <i>drumstick</i> | paygay <i>pillow</i> | pekom <i>bear</i> | tungdae <i>lighthouse</i> | |
| hita <i>heater</i> | hooshik <i>dessert</i> | hayum <i>swim</i> | habit <i>sun</i> | hooksek <i>black</i> | |

The English words were spoken by a female native English speaker (age: 31) and the Korean words by a female native Korean speaker (age: 26). The speakers recorded three repetitions of each word as written on individual cue cards randomly presented to them one at a time. In this and subsequent experiments, a unidimensional head-mounted microphone (Shure SM10A) and DAT tape recorder (Sony TCD-D8) were

used. Each speaker's last rendition of each word was excised from the speech stream, ramped off during the first and last 15ms to remove audible clicks, and normalized for peak intensity and perceived loudness.

2.3

Procedure

The participants were tested individually in a quiet room or sound-attenuated booth. A picture-naming task was used to elicit the English and Korean words and the audio stimuli were presented using presentation software (Smith, 1997). The participants produced only the words of their native language. The meaning of each word was depicted in a simple line drawing. The drawings were presented to the participants three times in randomized sets. As the first set of pictures was presented, the participants heard the name of the picture over loudspeakers as spoken by either the native English or Korean speaker and repeated the word. As the second and third sets were presented, the participants were asked to remember the name of the picture and to say it upon seeing the picture. The participants were thus not merely shadowing (imitating) the female speaker but were attempting to phonologically encode the perceived word. If the participants were unable to recall the name of the picture, they heard the speaker's model again and then repeated the word. Such instances in both the current and the subsequent experiment accounted for less than 1% of the total number of productions (fewer than 5 words in the current experiment) and were not over-represented on any single item. The productions of the 360 English (20 monolinguals \times 18 words) and 200 Korean (20 Korean monolinguals \times 10 Korean words) words spoken in the third set were digitized at 16 kHz, excised from the speech stream, and submitted to an acoustic analysis.

2.4

Data analysis

Acoustic analyses of the English and Korean words were performed to determine how similar (or different) the six English and five Korean vowels were across the two languages. The data were analyzed acoustically because most bilingual vowel-production studies have employed acoustic analyses (see, e.g., Flege, Schirru, & MacKay, 2003, and Guion, 2003), thus allowing for comparisons of findings across studies. Other measures, such as listener judgments (i.e., where native speakers rate the accuracy of the participants' productions on a typically 7-point Likert scale), were not used because perceptual judgments made by either trained or untrained listeners would only allow for documenting relatively large differences in production accuracy. That is, such judgments would be able to determine whether speakers make a distinction between qualitatively different vowels such as Korean /i/ and English /i/, but would be less likely to determine whether speakers make a distinction between qualitatively similar vowels such as Korean /i/ and English /i/.

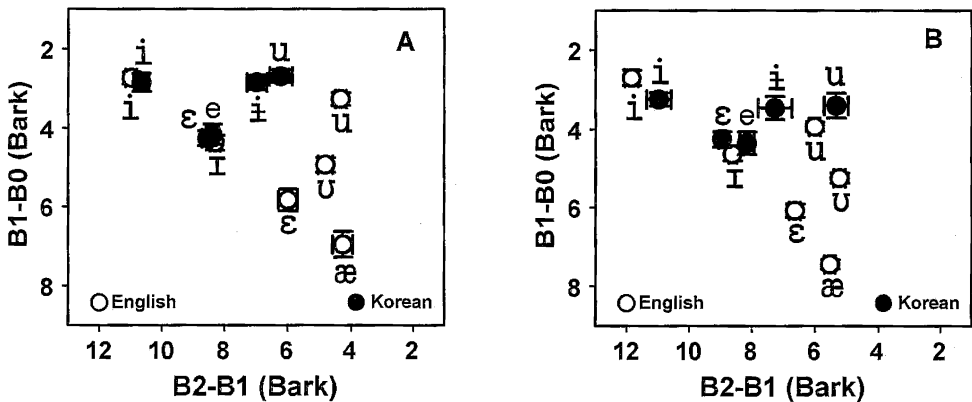
Acoustic analyses of English and Korean vowels were restricted to the analyses of the first two vowel-formant frequencies. Although it is possible that the two languages may differ significantly in other dimensions of vowel acoustics (e.g., vowel duration or diphthongization) and that bilinguals may capitalize on these differences to make

distinctions across their two languages, analyses of these vowel properties were not possible within the present study because of the differences in syllable length across the word sets in the two languages. More specifically, the vowels were analyzed by measuring fundamental frequency (F_0) as well as the first two vowel formants (F_1 , F_2) at both vowel onset and vowel midpoint. The vowels were measured both by hand and by pitch and LPC measurements using BLISS (Brown Laboratory Interactive Speech System, Mertus, 2001). Only the measurements at vowel midpoint were used in the analysis. Each data point for each vowel represented a mean of respective frequency values across three tokens of English vowels measured in three English words and two tokens of Korean vowels measured in two Korean words.

The vowel-formant values (in Hz) were converted to Bark scale (B) to normalize for gender and age differences in vowel production (Syrdal & Gopal, 1986) by using the following formula: $B = 26.81 / (1 + (1960 / F)) - 0.53$. Two additional measures were derived from the obtained vowel-formant values: B1-B0 (B1 minus B0) and B2-B1 (B2 minus B1). B1-B0 is an estimate of vowel position in the high-low dimension, where lower values represent high vowels and higher values represent low vowels. B2-B1 is an estimate of vowel position in the front-back dimension, where lower values represent back vowels and higher values represent front vowels. (See Appendix for English and Korean monolinguals' vowel-formant values.) The vowels were then plotted in the acoustic space with B2-B1 values on the X-axis and B1-B0 values on the Y-axis (Fig. 1).

Figure 1

Mean acoustic values of English and Korean vowels produced by English and Korean adult (A) and child (B) monolinguals. Brackets enclose 2 *SE*



2.5 Results

Previous research on perceived similarity between English and Korean vowels (Baker et al., 2001; Trofimovich et al., 2001) and visual inspection of the data were used to initially categorize the English and Korean vowels into subsets for the subsequent

statistical analyses. In particular, three different areas of the vowel space appeared to have acoustically similar vowels: (a) high-front vowels (Korean /i/ and English /i/, /ɪ/), (b) high-back vowels (Korean /u/, /ɨ/ and English /u/, /ʊ/), and (c) low-front vowels (Korean /e/, /ɛ/ and English /æ/, /ɛ/). Visual inspection of the data also suggested that English /ɪ/ may overlap with Korean /e/ and /ɛ/; to explore this possibility, comparisons were made among these and the remaining low-front vowels as well.

Independent-samples *t*-tests were used to carry out cross-language comparisons of vowels produced by the English and Korean child and adult monolinguals. Compared within each of the three vowel sets (in separate *t*-tests) were both vowel height (B1-B0) and vowel frontedness (B2-B1) values, first for the groups of English and Korean adult monolinguals and then for the groups of English and Korean child monolinguals. For example, separate *t*-tests compared the vowel height and vowel frontedness values between the English adults' English /i/ and the Korean adults' Korean /i/ as well as between the English adults' English /ɪ/ and the Korean adults' Korean /i/. Four other *t*-tests were used to compare the vowel height and vowel frontedness values between the same pairs of English and Korean vowels produced by the English and Korean children, respectively. The alpha level for significance was set at .002 because 24 pairwise comparisons were carried out between the groups of English and Korean children and adults.

These analyses revealed the following findings. First, two of the English-Korean vowel pairs completely overlapped acoustically in both children's and adults' productions: English /i/ did not differ acoustically from Korean /i/, and English /ɪ/ did not differ acoustically from either Korean /e/ or /ɛ/, in either vowel height or vowel frontedness. These latter results also indicated that Korean /e/ and /ɛ/ completely overlapped in the Korean children's and adults' vowel space. This finding is not surprising given that these vowels are no longer distinguished as phonemic by speakers of the Seoul dialect of Korean, the dialect from which most of the participants were pooled (Lee & Ramsey, 2000; Sohn, 1999). Of the 20 native Korean participants, only two were not from the Seoul area. An inspection of these participants' productions of Korean /e/ and /ɛ/ did not seem to indicate that there was a difference between their and the remaining participants' production of these vowels.

Second, two English vowels—English /æ/ and /ɛ/—occupied a part of the phonetic space not occupied by any other vowels across the two languages. In particular, these two English vowels differed significantly from Korean vowels in both vowel height and vowel frontedness in both children's and adults' productions: (a) English /ɛ/ differed from Korean /e/ and /ɛ/, $t_s(18) > 4.45$, $ps < .0001$, and (b) English /æ/ differed from Korean /e/ and /ɛ/, $t_s(18) > 6.79$, $ps < .0001$. That is, two of the six English vowels (English /æ/ and /ɛ/) were dissimilar acoustically from the Korean vowels with which they were paired.

Finally, English /u/, /ʊ/ and Korean /u/, /ɨ/ constituted a complex relationship across the two languages. The least similar vowel in this group was English /ʊ/. In both the children's and the adults' productions, English /ʊ/ did not overlap with either Korean /u/ or Korean /ɨ/ in vowel height, $t_s(18) > 5.39$, $ps < .0001$, but did in vowel frontedness. By contrast, English /u/ was more similar to the Korean vowels. For both the adults and the children, English /u/ overlapped with Korean /ɨ/ in vowel

height and vowel frontedness. English /u/ also overlapped with Korean /u/ in both vowel height and vowel frontedness for the children, but only in vowel height for the adults, $t_s(18) > 4.77$, $ps < .0001$.

2.6

Discussion

The results of this experiment determined the acoustic properties of English and Korean vowels, as spoken by English and Korean monolingual children and adults. Three main findings emerged. First, two English-Korean vowel pairs (English /i/-Korean /i/ and English /ɪ/-Korean /e/, /ɛ/), overlapped completely in the vowel space. Second, two English vowels (English /æ/ and /ɛ/) occupied distinct areas of the vowel space. Finally, two English-Korean vowel pairs (English /u/, /ʊ/-Korean /u/, /ɨ/) had acoustic values that partially overlapped in a complex relationship that differed for the child versus adult monolinguals.

These findings accorded well with the results of perceptual (Baker et al., 2001; Trofimovich et al., 2001) and acoustic (Yang, 1996) comparisons of these same vowels and, more importantly, suggested that the English-Korean vowel pairs examined in this experiment would fall into the following groups (from easiest to most difficult) with respect to Korean-English bilinguals' ability to produce them with distinct acoustic properties: (a) English /æ/-Korean /e/, English /ɛ/-Korean /ɛ/, English /ɪ/-Korean /i/, (b) English /u/, /ʊ/-Korean /u/, /ɨ/, and (c) English /i/-Korean /i/, English /ɪ/-Korean /e/, /ɛ/. (Although the findings of this study indicated that English /ɪ/ overlapped in the vowel space with Korean /e/, /ɛ/, suggesting that these three vowels should therefore be grouped together, perceptual studies indicate that Koreans tend to identify English /ɪ/ with Korean /i/, Trofimovich et al., 2001; therefore, English /ɪ/ was compared with both Korean /e/, /ɛ/ and Korean /i/ in all further analyses.)

3 Experiment 2: Korean-English bilinguals

The objective of this experiment was to compare how early and late Korean-English bilinguals, who also differed in amount of experience with their L2, produce English and Korean vowels (bilingual comparisons), and how their productions differ from those of monolingual speakers of English and Korean (monolingual comparisons). These two comparisons determined the degree (bilingual comparisons) and direction (monolingual comparisons) of L1-L2 interaction. The following two hypotheses were examined: (1) the amount of similarity between L1 and L2 sounds would determine the degree and direction to which early and late bilinguals' L1 and L2 influence each other, and (2) the degree and direction of this influence would be greater in the beginning than in advanced stages of L2 learning.

3.1

Participants

The participants were 40 Korean-English bilinguals assigned to one of four groups ($n = 10$) depending on their age at onset of English learning and length of U.S. residence (Table 3).

3.1.1

Late bilinguals

Two of the groups were composed of late bilinguals who differed in their amount of experience with English (defined as length of U.S. residence). The first of these groups, the Late +1 group (where '+1' indicates about 1 year of U.S. residence), arrived in the U.S. at a mean age of 24.9 (18–31 years), were on average 25.8 years old (19–32 years), and had been exposed to English in the U.S. for about 11 months (7.0–1.5 months). The second group, the Late +7 group (where '+7' indicates about 7 years of U.S. residence), arrived in the U.S. at a mean age of 22.6 (15–30 years), were on average 29.5 years old (19–35 years), but had been exposed to English in the U.S. much longer, for about seven years (5–15 years). These two groups did not differ from each other in age of arrival in the U.S., $t(18)=1.08$, $p = .29$, but differed in length of U.S. residence, $t(18)=7.89$, $p < .001$.

TABLE 3Means and *SDs* (in parentheses) for participant variables in Experiment 2

| Group | <i>Age</i> ^a | <i>AOA</i> ^b | <i>LOR</i> ^c | <i>K. Use</i> ^d | <i>K. Rate</i> ^e | <i>E. Rate</i> ^f |
|-----------------|-------------------------|-------------------------|-------------------------|----------------------------|-----------------------------|-----------------------------|
| Late +1 (n=10) | 25.8 (1.5) | 24.9 (1.7) | 0.9 (0.3) | 57% | 10.0 (0.0) | 6.1 (1.9) |
| Late +7 (n=10) | 29.5 (6.8) | 22.6 (5.1) | 6.9 (3.3) | 55% | 10.0 (0.0) | 6.7 (1.8) |
| Early +1 (n=10) | 10.2 (1.9) | 8.9 (2.0) | 1.3 (0.4) | 46% | 9.4 (1.3) | 5.5 (1.5) |
| Early +7 (n=10) | 16.9 (3.3) | 8.8 (2.9) | 8.0 (0.7) | 42% | 7.3 (2.3) | 7.8 (2.0) |

^aAge at the time of testing, in years. ^bAge of arrival in the U.S., in years. ^cLength of U.S. residence, in years. ^dPercent of daily Korean use. ^eKorean self-rating from 1 to 10. ^fEnglish self-rating from 1 to 10.

3.1.2

Early bilinguals

Two other groups were composed of early bilinguals who also differed in their amount of experience with English. The first of these groups, the Early +1 group, arrived in the U.S. at a mean age of 8.9 (7–12 years), were on average 10.2 years old (7–12 years), and had been exposed to English in the U.S. for about one year (0.7–2.0 years). The second group, the Early +7 group, arrived in the U.S. at a mean age of 8.8 (7–13 years), were on average 16.9 years old (12–23 years), and had been exposed to English for about eight years (5–15 years). These two groups did not differ from each other in age of arrival in the U.S., $t(18)=.01$, $p = .94$, but differed in length of U.S. residence, $t(18)=9.90$, $p < .001$.

The participants rated their ability to speak, read, write, and comprehend English and Korean on the same scale used in Experiment 1. Three of the four bilingual groups did not differ from one another in their English self-rating but differed from the Early +7 group, who rated their English ability slightly higher, $F(3, 36)=8.19$, $p < .01$. In addition, the Early +7 group differed from the other three groups in their Korean self-rating, estimating their Korean proficiency slightly lower than the other

three groups, $F(3, 36) = 21.79, p < .001$. The four groups also estimated the amount of their daily use of Korean and appeared to use Korean to a comparable degree, $F(3, 36) = 1.15, p = .29$. Thus, of the demographic variables examined, the four groups differed mainly in their age at onset of L2 learning (early vs. late) and their length of U.S. residence (1 vs. 7 years). In addition, the Early + 7 group differed from the other bilinguals in their rating of English and Korean proficiency.

3.2

Stimuli, procedure, and data analysis

The stimuli and procedure utilized in this experiment were the same as those used in Experiment 1. The acoustic analyses in this experiment included 1120 words spoken by the Korean-English bilinguals (40 Korean-English bilinguals \times 18 English and 10 Korean words).

3.3

Results

The results of this experiment are presented in two sections. In the first section (bilingual comparisons), the bilinguals' own productions of English vowels were compared with their own productions of Korean vowels. This analysis established which vowels across the two languages the bilinguals produced with distinct acoustic properties and which they did not, thereby determining the degree of interaction of the L1 and L2. In the second section (monolingual comparisons), the bilinguals' productions of English and Korean vowels were compared with the English and Korean monolinguals' productions of the same vowels (Experiment 1), respectively. This analysis examined to what extent the bilinguals' vowels differed from those of English and Korean monolinguals, thereby determining the direction of the L1-L2 influence. (See Appendix for the early and late bilinguals' vowel-formant values.)

3.3.1

Bilingual comparisons

Late bilinguals. First analyzed were the vowels produced by the Late + 1 and Late + 7 groups. In these analyses, two sets of two-way repeated-measures ANOVAs (followed by Bonferroni tests—*t*-tests with alpha adjusted for number of pairwise comparisons) were conducted, one which compared the B1-B0 (vowel height) and one which compared the B2-B1 (vowel frontedness) values within each of the two groups (Late + 1, Late + 7). For these analyses, the vowels were categorized into the same three sets used in Experiment 1: (a) three high-front vowels (English /i/, /ɪ/ and Korean /i/), (b) four high-back vowels (English /u/, /ʊ/ and Korean /u/, /ɨ/), and (c) four low-front vowels (English /æ/, /ɛ/ and Korean /e/, /ɛ/) and one high-front vowel (English /ɪ/). For example, the B1-B0 and B2-B1 scores for the vowels within each set were examined in two separate two-way repeated-measures ANOVAs with group (Late + 1, Late + 7) as between- and vowel (e.g., English /i/, /ɪ/, Korean /i/) as within-subjects factors, with follow-up Bonferroni tests comparing—within each group—vowel height and vowel frontedness values between pairs of vowels (e.g., English /i/-Korean /i/, English /ɪ/-Korean /i/, English /i/-English /ɪ/). The goal of these analyses was to determine

whether the late bilinguals maintained acoustic distinctions between the English and Korean vowels, which would suggest that they had separate categories for them and would indicate the degree of L1-L2 interaction.

These analyses revealed that, for the high-front and high-back vowels, there was little distinction in vowel acoustic properties across the two languages. In particular, two-way repeated-measures ANOVAs with group (Late + 1, Late + 7) as between- and vowel (English /i/, /ɪ/, Korean /i/) as within-subjects factors yielded no significant main effects of group or vowel nor a significant group \times vowel interaction. This finding obtained in the analyses of both the vowel height and vowel frontedness values, suggesting that the late bilinguals produced these vowels with similar acoustic properties. In effect, the Late + 1 and Late + 7 groups had one vowel category that encompassed these three high-front vowels. Similar two-way repeated-measures ANOVAs with group (Late + 1, Late + 7) as between- and vowel (English /u/, /ʊ/, Korean /u/, /ɨ/) as within-subjects factors yielded a significant main effect of group (in the B1-B0 analysis), $F(1, 18) = 5.09, p < .05$, a significant main effect of vowel (in the B2-B1 analysis), $F(3, 54) = 6.79, p < .001$, and a significant group \times vowel interaction (in the B1-B0 analysis), $F(3, 54) = 6.83, p < .001$. Follow-up Bonferroni tests ($\alpha = .004$), however, failed to reveal any statistically significant differences between the vowel height and vowel frontedness values of English and Korean vowels, suggesting that the bilinguals in the Late + 1 and Late + 7 groups produced the four vowels in this set (English /u/, /ʊ/, Korean /u/, /ɨ/) with similar acoustic properties.

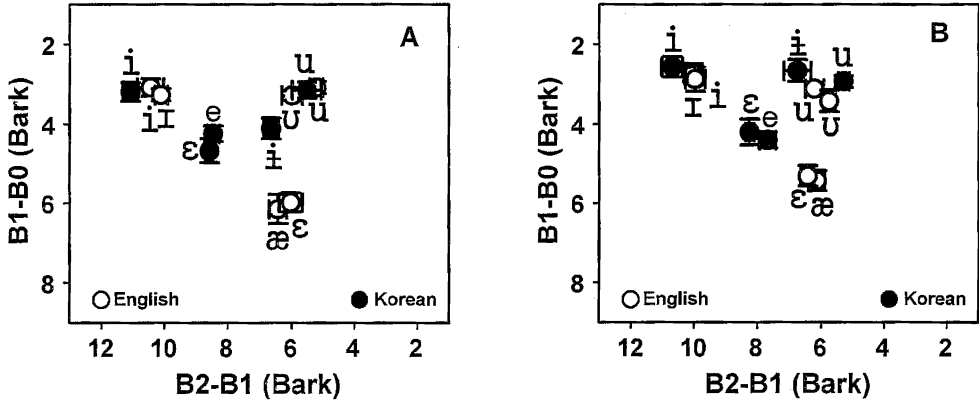
Finally, two-way repeated-measures ANOVAs with group (Late + 1, Late + 7) as between- and vowel (English /æ/, /ɛ/, /ɪ/, Korean /e/, /ɛ/) as within-subjects factors yielded only significant main effects of vowel, $F_s(4, 72) > 61.90, p < .0001$. Follow-up Bonferroni tests ($\alpha = .0025$) revealed that the two groups produced English /æ/, /ɛ/ and Korean /e/, /ɛ/ with distinct acoustic properties, $ts(9) > 3.94, ps < .0025$, but neither group appeared to maintain a distinction between English /æ/ and /ɛ/ or between Korean /e/ and /ɛ/. Apparently, the late bilinguals had one merged vowel category for the English low-front vowels /æ/ and /ɛ/ and one for the Korean low-front vowels /e/ and /ɛ/. Moreover, both groups produced Korean /e/, /ɛ/ (and English /æ/, /ɛ/) with acoustic properties that were different from those of English /ɪ/, $ts(9) > 6.73, ps < .001$.

Taken together, these results indicated that the late bilinguals had what appeared to be a four-vowel system for the six English and five Korean vowels. They had (a) a high-front vowel category that encompassed English /i/, /ɪ/, and Korean /i/, (b) a high-back vowel category that encompassed English /u/, /ʊ/, and Korean /u/, /ɨ/, (c) a low-front vowel category that encompassed English /æ/ and /ɛ/, and (d) a mid-front vowel category that encompassed Korean /e/ and /ɛ/ (Fig. 2). Thus, the only “new” vowel category formed by the late bilinguals was the low-front category encompassing English /æ/ and /ɛ/, or the two English vowels that were the least similar to Korean vowels (based on results of Experiment 1). These findings suggested a certain degree of interaction between the late bilinguals’ English and Korean vowels.

Early bilinguals. The above analyses indicated how late bilinguals organized their English and Korean vowel system(s). Similar analyses were performed to investigate how early bilinguals (Early + 1, Early + 7) organized their vowel system(s). Again,

Figure 2

Mean acoustic values of English and Korean vowels produced by the Late + 1 (A) and the Late + 7 (B) groups of adult bilinguals. Brackets enclose 2 *SE*



each group's productions of English and Korean vowels (organized in 3 vowel sets) were analyzed using two-way repeated-measures ANOVAs and follow-up Bonferroni tests. These analyses revealed the following findings. First, two-way repeated-measures ANOVAs with group (Early + 1, Early + 7) as between- and vowel (English /i/, /ɪ/, Korean /i/) as within-subjects factors yielded significant main effects of vowel, $F_s(2, 36) > 19.12$, $ps < .0001$, and a significant main effect of group (in the B1-B0 analysis), $F(1, 18) = 8.52$, $p < .01$. Follow-up Bonferroni tests ($\alpha = .008$) revealed that both groups produced acoustic differences between English /i/ and /ɪ/, $ts(9) > 5.02$, $ps < .001$, and that neither group produced acoustic differences between English /i/ and Korean /i/. These tests also revealed that the Early + 7 group, but not the Early + 1 group, produced English /ɪ/ with acoustic properties that were different from Korean /i/, $ts(9) > 4.32$, $ps < .002$.

Second, two-way repeated-measures ANOVAs with group (Early + 1, Early + 7) as between- and vowel (English /u/, /ʊ/, Korean /u/, /ɯ/) as within-subjects factors yielded significant main effects of vowel, $F_s(3, 54) > 9.59$, $ps < .0001$, group (in the B1-B0 analysis), $F(1, 18) = 20.14$, $p < .0001$, and significant group \times vowel interactions, $F_s(3, 54) > 3.15$, $ps < .05$. Follow-up Bonferroni tests ($\alpha = .004$) revealed that, of the four high-back vowels, the Early + 1 group produced three (English /u/, /ʊ/, Korean /u/) with similar acoustic properties, all distinct from those of Korean /ɯ/, $ts(9) > 4.64$, $ps < .001$. These tests also revealed that the Early + 7 group produced English /u/ and Korean /u/ with similar acoustic properties, while maintaining a distinction between English /ʊ/ and both English and Korean /u/, $ts(9) > 4.16$, $ps < .002$, as well as between Korean /ɯ/ and the other three vowels, $ts(9) > 4.67$, $ps < .001$.

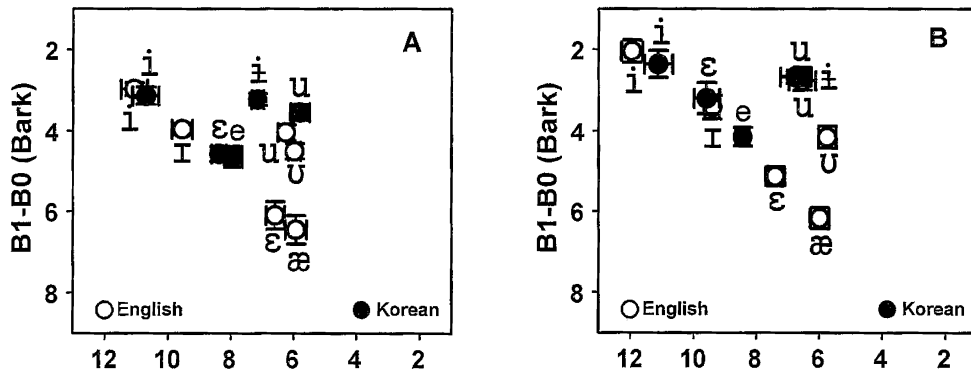
Finally, two-way repeated-measures ANOVAs with group (Early + 1, Early + 7) as between- and vowel (English /æ/, /ɛ/, /ɪ/, Korean /ɛ/, /ɛ/) as within-subjects factors yielded significant main effects of vowel, $F_s(4, 72) > 49.83$, $ps < .0001$, and group (in the B1-B0 analysis), $F(1, 18) = 7.60$, $p < .025$, but no significant interactions. Follow-up Bonferroni tests ($\alpha = .0025$) revealed that the Early + 1 group collapsed

English /æ/ and /ɛ/ as well as Korean /e/ and /ɛ/ into two single vowel categories but that they maintained a distinction between both English /æ/, /ɛ/ and Korean /e/, /ɛ/, $t_s(9) > 5.33$, $ps < .001$. These tests also revealed that the Early +7 group produced English /æ/ significantly differently from English /ɛ/, and produced these two English vowels significantly differently from Korean /e/ and /ɛ/, $t_s(9) > 4.43$, $ps < .002$, for which they did not maintain a distinction. Unlike the late bilinguals, the two early bilingual groups produced English /ɪ/ with acoustic properties that overlapped with Korean /e/ and /ɛ/.

These results indicated that the bilinguals in the Early +1 group had what appears to be a five-vowel system for the six English and five Korean vowels: (a) a high-front vowel for English /i/ and Korean /i/, (b) a high-front vowel for English /ɪ/ and Korean /e/, /ɛ/, (c) a high-back vowel for English /u/, /ʊ/ and Korean /u/, (d) a high-back vowel for Korean /ɨ/, and (e) a low-front vowel for English /æ/ and /ɛ/. The bilinguals in the Early +7 group differed from those in the Early +1 group in that they had three separate vowel categories for English /ʊ/, /æ/ and /ɛ/, for a total of seven vowel categories across their languages (Fig. 3).

Figure 3

Mean acoustic values of English and Korean vowels produced by the Early +1 (A) and the Early +7 (B) groups of child bilinguals. Brackets enclose 2 SE



3.4

Discussion

This analysis sought to examine how Korean-English bilinguals organize their phonetic system(s) for a subset of English and Korean vowels and the degree to which the two languages influence each other. The results of bilingual comparisons revealed that cross-language similarity influenced how bilinguals organized their two languages and that such an influence was more pronounced for the late than for the early bilinguals. All four groups of bilinguals produced acoustic differences between Korean /e/, /ɛ/ and English /æ/, /ɛ/, the vowels that were dissimilar across the two languages. Unlike the early bilinguals, the late bilinguals, however, produced English /ɪ/, /i/ and /ʊ/, /u/ with acoustic values that overlapped with perceptually

(Baker et al., 2001; Trofimovich et al., 2001) and acoustically (Yang, 1996) similar Korean /i/ and /u/, respectively. That is, the late bilinguals were able to separate their two languages when L1 and L2 sounds were dissimilar across the two languages, but when the sounds were similar across the two languages, they produced English and Korean vowels with similar acoustic properties. By contrast, the early bilinguals were able to maintain distinctions between English and Korean vowels except when their acoustic properties were completely overlapping (as in English /i/-Korean /i/ and English /ɪ/-Korean /e/, /ɛ/), suggesting that cross-language similarity may play a greater role in determining whether or not the late bilinguals, as opposed to the early bilinguals, maintain distinctions between L1 and L2 vowels.

The results of bilingual comparisons also revealed that the influence of L2 experience differed between the early and late bilinguals. For the late bilinguals, amount of L2 experience appeared to play little role in determining whether or not the late bilinguals were able to maintain distinctions between English and Korean vowels. The Late + 1 and Late + 7 groups did not differ in their abilities to produce acoustic differences in English and Korean vowels. By contrast, amount of experience did determine whether the early bilinguals were able to separate the two languages. More specifically, the bilinguals in the Early + 7 group differed from those in the Early + 1 group in that they were able to produce distinctions between English /æ/ and /ɛ/ as well as between English /u/ and /ʊ/, vowels that are often confused perceptually by native Korean speakers (Flege, Bohn, & Jang, 1997; Ingram & Park, 1997).

Although these findings reveal differences in the degree of L1-L2 interaction between early and late bilinguals, these results did not reveal the directionality of the L1-L2 influence. For example, the early bilinguals collapsed the two Korean vowels /e/, /ɛ/ into a single vowel category that also encompassed English /i/. This finding may suggest that the early bilinguals' L2 (English) may have influenced the production of their L1 (Korean). However, this finding may also suggest that the early bilinguals' L1 influenced the production of their L2. Based on bilingual comparisons alone, it would be difficult to know whether the differences in overlap found across ages was the result of English vowels influencing Korean vowels or Korean vowels influencing English vowels. Thus, in the next analysis, a comparison of English and Korean vowels produced by Korean and English monolinguals (Experiment 1) and by Korean-English bilinguals was conducted to determine the direction of the L1-L2 influence.

3.4.1

Monolingual comparisons

The above analyses determined which vowels the bilinguals were able to produce with distinct (non-overlapping) acoustic properties and determined the degree to which they were able to do so. The following analysis determined which of those vowels were produced in a monolingual-like manner, thus establishing the direction of influence in L1-L2 interaction, by comparing the English and Korean vowels produced by the bilinguals to the same vowels produced by the English and Korean monolinguals.

Late bilinguals. First analyzed were the five Korean vowels (/i/, /u/, /e/, /ɛ/, /ɪ/) produced by the K Adult, Late + 1, and Late + 7 groups. In these analyses, two sets

of one-way ANOVAs (followed by Tukey HSD post-hoc tests) were conducted—one comparing the B1-B0 (vowel height) and the other comparing the B2-B1 (vowel frontness) values for each of the five vowels across the three groups. These analyses revealed that the late bilinguals did not differ from the Korean monolingual adults in their production of any of the Korean vowels, suggesting that the late bilinguals' Korean vowels were unaffected by learning English. Even after extensive experience with English (about 7 years of U.S. residence), the Korean vowels produced by the late bilinguals were similar in acoustic properties to the Korean vowels produced by the Korean monolingual adults.

The six English vowels (/i/, /ɪ/, /e/, /æ/, /u/, /ʊ/) produced by the E Adult, Late + 1, and Late + 7 groups were analyzed next using similar one-way ANOVAs. These analyses revealed that the late bilinguals did not differ from the English monolingual adults in their productions of three English vowels (/e/, /u/, /i/), but differed from them in their production of the remaining three vowels (/ɪ/, /æ/, /ʊ/), $F_s(2, 27) > 5.83$, $p_s < .008$. In particular, the late bilinguals produced the two high lax vowels (English /ɪ/, /ʊ/) and the low-front vowel (English /æ/) higher and more anterior in the vowel space than did the English monolingual adults and therefore more similarly to Korean /i/, /u/, and /e/, respectively. This finding indicated that the late bilinguals' L1 (Korean) categories, even after seven years of experience using English, exhibited a profound effect on the production of L2 (English) vowels.

Early bilinguals. As in the analyses of the late bilinguals' vowel production, first analyzed in one-way ANOVAs were the B1-B0 and the B2-B1 values for the five Korean vowels (/i/, /e/, /ɛ/, /u/, /ɨ/) produced by the K Child, Early + 1, and Early + 7 groups. In this and the following analyses, the bilingual groups were compared to the group of monolingual children because monolingual children's production of vowels represented the "initial" state of the bilinguals' L1 and the "target" state of the bilinguals' L2 at the onset of L2 learning. These analyses revealed that the Early + 1 group did not differ from the Korean monolingual children in their production of any of the vowels, but that the Early + 7 group differed from the Korean monolingual children in their production of three Korean vowels (/i/, /u/, /e/), $F_s(2, 27) > 3.56$, $p_s < .05$. In particular, the Early + 7 group produced Korean /i/, /u/, and /e/ higher in the vowel space and, in the case of Korean /u/, also more anterior than the Korean monolingual children did. These findings suggested that, after an extensive experience with English, the early bilinguals' L1 (Korean) vowels were "colored" by L2 (English) vowels.

The B1-B0 and B2-B1 measurements for the six English vowels (/i/, /ɪ/, /e/, /æ/, /u/, /ʊ/) produced by the E Child, Early + 1, and Early + 7 groups were analyzed next using similar one-way ANOVAs. These analyses revealed that the early bilinguals did not differ from the English monolingual children in their production of English /i/, /u/, or /e/ but that they differed from the English monolingual children in their production of English /ɪ/, /ʊ/, and /æ/, $F_s(2, 27) > 6.54$, $p_s < .005$. More specifically, the early bilinguals (in both the Early + 1 and Early + 7 groups) produced English /ɪ/, /ʊ/, and /æ/ higher in the vowel space than did the English monolingual children. This finding suggested that the early bilinguals' production of at least some of the L2 vowels was influenced by their L1.

3.5

Discussion

This analysis provided insights into how cross-language similarity influenced the direction of L1-L2 interaction in early and late bilinguals. For the late bilinguals, there was a unidirectional influence of the L1 on the L2, which was heavily determined by cross-language similarity. That is, when English and Korean vowels were relatively similar acoustically, the late bilinguals' renditions of L2 (English) vowels were strongly "colored" by the acoustic properties of their L1 (Korean) vowels. There was little evidence of the influence of the L2 on the L1 in the late bilinguals—they produced all L1 (Korean) vowels with the acoustic properties typical of Korean monolinguals' renditions of the same vowels. By contrast, for the early bilinguals, there was a bidirectional L1-L2 influence, which was not heavily determined by cross-language similarity. That is, whether or not English and Korean vowels were relatively similar or dissimilar acoustically, the early bilinguals' renditions of at least some L2 (English) and L1 (Korean) vowels were "colored" by the acoustic properties of their L1 and L2 vowels, respectively.

This analysis also indicated how amount of L2 experience influenced the direction of L1-L2 interaction in early and late bilinguals. For the late bilinguals, evidence of the unidirectional influence of the L1 on the L2 was found not only in the beginning (within about 1 year of U.S. residence), but also in more advanced (within about 7 years of U.S. residence) stages of L2 learning. Apparently, the amount of experience using an L2 did not influence how the late bilinguals produced L1 vowels, regardless of the degree of perceptual (Baker et al., 2001; Trofimovich et al., 2001) and acoustic (Yang, 1996) similarity between English and Korean vowels. By contrast, for the early bilinguals, evidence of the bidirectional L1-L2 influence was found in more advanced stages of L2 learning. Whereas the late bilinguals' L1 (Korean) exerted a comparable amount of influence on their L2 (English) in both the beginning and more advanced stages of L2 learning, the early bilinguals' L2 manifested its influence on their L1 only in more advanced stages of L2 learning.

4 General Discussion

The main objective of this study was to provide a comprehensive view of how early and late bilinguals' phonetic system(s) interact by comparing Korean-English bilinguals' productions of English (L2) and Korean (L1) vowels to each other (bilingual comparisons) and to Korean and English monolinguals' productions of the same vowels (monolingual comparisons). More specifically, the overall goal of this study was to examine how three specific variables influenced bilingual phonetic system(s): age at the time of L2 acquisition (age), degree of cross-language similarity (similarity), and amount of L2 experience (experience). The results of this study indicated that each of these factors profoundly influenced both the degree (as determined by bilingual comparisons) and the direction (as determined by monolingual comparisons) of L1-L2 interaction in the Korean-English bilinguals.

4.1

Age

Age at the time of L2 acquisition influenced both the degree and the direction of the L1-L2 interaction. In particular, the results of this study indicated that the degree of the L1-L2 influence on the early bilinguals was different from that on the late bilinguals. The early bilinguals were able to produce distinct acoustic realizations of L1 and L2 vowels to a greater degree than were the late bilinguals. In fact, the only English-Korean vowel pairs for which the early bilinguals did not produce acoustic differences were those that were completely overlapping in the acoustic space. These findings were in accord with previous studies which found that the earlier the exposure to both languages, the more likely a bilingual will produce distinct acoustic realizations of L1 and L2 sounds (Flege et al., 2003; Guion, 2003). The results of this study also indicated that the direction of the L1-L2 influence was different in the early and in the late bilinguals. The early bilinguals manifested a bidirectional influence while the late bilinguals manifested a unidirectional L1 influence on the L2. That is, for the late bilinguals, L2 (English) did not influence how L1 (Korean) was produced, but L1 (Korean) profoundly influenced how L2 (English) was produced.

Examining the results of bilingual and monolingual comparisons provides insight into how age at the time of L2 acquisition influences the L1-L2 relationship. What seems to be restructured in the process of L2 learning in late bilinguals is their L2 alone—this occurred under a heavy influence of their L1. It appears that late bilinguals may rely on L1-based sound categories and may use them to process both L1 and L2 sounds. By contrast, there seems to be a phonetic restructuring of both languages in early bilinguals, at least in those who have used their L2 for about seven years. In the case of those L2 vowels that are dissimilar or are similar to, but not completely overlapping with, L1 vowels, early bilinguals may create a “new” L2 vowel category so that it remains distinct from any other L1 or L2 vowel (Flege et al., 2003). By contrast, for very similar L1-L2 vowels, early bilinguals appear to create merged L2-based categories (Mack, 1990; Mack et al., 1995).

4.2

Cross-language similarity and amount of L2 experience

In addition, the results of this study complemented the findings of previous research on age and L2 learning by demonstrating that variables such as cross-language similarity (acoustic similarity between L1 and L2 vowels) and amount of L2 experience (length of residence in the target-language country) determined how the early and late bilinguals organized their two languages. In examining the effect of these two variables on L1-L2 interaction in early and late bilinguals, two hypotheses were proposed: (1) the amount of similarity between L1 and L2 sounds would determine the degree and direction to which early and late bilinguals’ L1 and L2 influence each other, and (2) the extent of such a bidirectional influence (interaction) would be greater in the beginning than in the advanced stages of L2 learning.

In response to the first hypothesis, the results of this study indicated that cross-language similarity indeed influenced how both the L1 and L2 are produced. That is, vowels that were highly similar across the two languages were more likely to influence

each other than those vowels that were dissimilar. However, cross-language similarity interacted with, or was influenced by, age at the time of L2 acquisition. Thus, cross-language similarity was more likely to influence the late than the early bilinguals. The late bilinguals produced acoustic differences only for those L1-L2 vowel pairs that were highly dissimilar. By contrast, the early bilinguals produced acoustic differences between all L1-L2 vowel pairs (although not necessarily with the same acoustic properties as native speakers did) except for those L1-L2 vowel pairs that completely overlap in the acoustic space. Assuming that L1-L2 interaction implies restructuring of the L1 and L2 phonetic system(s), then the degree of perceptual similarity between L1 and L2 sounds constrains what sounds undergo such a restructuring and, if such a restructuring indeed occurs, the degree to which it does so. Early bilinguals seem to be able to largely overcome this constraint whereas late bilinguals seem to be heavily influenced by it (Baker et al., 2001; Walley & Flege, 1999). Further research examining how cross-language similarity influences the perception of the L1 and L2 in early and late bilinguals may indicate to what extent this ability constrains both the perception and the production abilities of bilinguals.

In response to the second hypothesis, the results of this study suggested that amount of L2 experience also influenced the L1-L2 relationship, although the extent of this influence also depended on the learners' age at the time of L2 acquisition. In this case, the influence of amount of L2 experience on the L1-L2 relationship played a greater role in the early than in the late bilinguals, a finding opposite to that obtained for cross-language similarity. More specifically, the late bilinguals with one year of U.S. residence did not differ from those with seven years of U.S. residence in how they produced their L1 and L2 vowels. In other words, amount of L2 experience influenced the late bilinguals' L1-L2 relationship very little. It is possible that late bilinguals may need a substantially more extensive amount of experience with an L2—perhaps in excess of 20 years, at least for some pairs of L1 and L2 sounds (Flege, Takagi, & Mann, 1995)—in order to reorganize their L1 and L2 phonetic system(s).

By contrast, the early bilinguals, even at initial stages of L2 learning, were more likely than were the late bilinguals with a similar amount of L2 experience to produce L1 and L2 vowels with distinct acoustic properties. This finding is important because few studies have examined early bilinguals at initial stages of L2 learning and is even more striking considering that the early bilinguals reported using their L2 as often as did the late bilinguals. The early bilinguals with seven years of U.S. residence were also more likely to produce L1 and L2 vowels with distinct acoustic properties than were the early bilinguals with only one year of U.S. residence. This finding suggested that early bilinguals not only have an initial advantage over late bilinguals in L2 phonetic learning (Bosch & Sebastián-Gallés, 2000; Pallier, Bosch, & Sebastián-Gallés, 1997) but that they also progress more rapidly through it than late bilinguals do (cf. Snow & Hoefnagel-Höhle, 1978). More importantly, the early bilinguals with seven years of U.S. residence produced L1 and L2 vowels that were more susceptible to bidirectional influences than were the vowels produced by the early bilinguals with one year of U.S. residence. In fact, influences of the L2 on the L1 were found only for the early bilinguals with seven years of U.S. residence, not for any of the other groups. This finding is suggestive—it indicates that bilinguals

are not like monolinguals of either of their languages, at least with respect to L1-L2 phonetic system(s) (Grosjean, 1985, 1989; Mack, 2003).

4.3

Bilinguals' phonetic system(s)

These findings create a comprehensive picture of many variables that determine how bilinguals organize their phonetic system(s). How can these findings be explained? According to Flege's Speech Learning Model (SLM), one possible explanation for early versus late bilingual differences in L2 speech learning is that the L1 and L2 interact differently depending on the age at which the L2 is learned (Flege, 1995). This tenet of the SLM, termed the *interaction hypothesis* (Flege, 1999; Flege, 1992; Walley & Flege, 1999), holds that bilinguals' L1 and L2 are less likely to interact (and therefore influence each other) in younger than in older learners. This is because younger learners' L1 is still developing (Hazan & Barrett, 2000; Sharma et al., 2001) and is therefore less likely to influence their L2 at the time when learners are exposed to it. The finding of this study that the L1 was more likely to influence the late than the early bilinguals' production of L2 vowels is in accord with this claim. By extension, this claim is also in agreement with the finding of this study that the L2 was more likely to influence the early than the late bilinguals' production of L1 vowels. Indeed, younger learners' L1 — because it is still developing — is also more susceptible than older learners' L1 to the influence of their L2. In other words, because early bilinguals' L1 sound categories are more flexible than those of late bilinguals, early bilinguals may be more likely than late bilinguals to restructure their L1 phonetic system and also develop new phonetic categories for L2 sounds, demonstrating a bidirectional L1-L2 influence. Similarly, because late bilinguals' L1 sound categories are fully "developed" when the L2 is learned, their L1 is more likely to influence the L2 and is also more resistant to the influence of the L2, revealing a unidirectional L1-to-L2 influence.

Flege's interaction hypothesis may also explain why cross-language similarity is more likely to determine how late than early bilinguals organize their phonetic system(s) and why amount of L2 experience is more likely to influence early than late bilinguals. Because early bilinguals' L1 categories are more malleable than late bilinguals' L1 categories, early bilinguals should be more likely than late bilinguals to produce even perceptually similar L1 and L2 sounds with distinct acoustic properties (Baker et al., 2001) and to perceive such L1 and L2 sounds in terms of distinct categories (Trofimovich et al., 2001; Walley & Flege, 1999). An increasing amount of experience with the L2 thus allows early bilinguals to capitalize on this initial learning advantage in order to restructure their (still malleable) L1 sound categories in order to accommodate L2 sounds. Because late bilinguals' L1 categories are fully developed, late bilinguals should be more likely than early bilinguals to produce even perceptually dissimilar L1 and L2 sounds with L1-based acoustic properties (Aoyama et al., 2003) and to perceive such L1 and L2 sounds in terms of an L1-based category (Guion et al., 2000; Trofimovich et al., 2001). Late bilinguals may require an amount of experience with the L2 that is far greater than that explored in this study in order to overcome the pervasive effect of their L1 on their processing and learning of L2 sounds (Flege et al., 1995).

The finding that the interaction between the L1 and L2 phonetic systems of child and adult bilinguals is at least one source of child-adult differences in L2 speech learning invites an important question regarding the origin of these child-adult differences. One fundamental source of these differences may lie in neurobiologically based age-related changes in the plasticity of brain structures underlying language learning and use (e.g., Kim, Relkin, Lee, & Hirsch, 1997). Although a “neural-plasticity” hypothesis cannot be ruled out, it is a difficult hypothesis to test given the multitude of factors involved and the methodology needed to do so. Another source of child-adult differences may relate to different patterns of children’s and adults’ language use, often resulting in child bilinguals’ switching their dominant language from their L1 to their L2 and in adult bilinguals’ maintaining their L1 as their dominant language (Jia & Aaronson, 2003). Whether or not patterns of language use and neurobiologically based age-related changes in neuronal plasticity determine the development of the L1-L2 phonetic system(s) in bilinguals, the interaction hypothesis—the hypothesis that child-adult differences in L2 speech learning are the result of the still-developing phonetic system of the child’s L1—appears a plausible (and perhaps more testable) hypothesis. While the main objective of this study was not to test this hypothesis, the interaction hypothesis certainly provides an explanation for the major findings of this study and suggests how and why L1-L2 restructuring differs in early and in late bilinguals. Further research encompassing measures of early and late bilinguals’ perceptual sensitivity to cross-language differences and their ability to perceive and produce such differences would provide stronger evidence for the interaction hypothesis and would further explain why the three variables discussed in this study (age, cross-language similarity, amount of experience) interact in the way that they do.

The findings of the present study overall provide evidence for the complex interaction between bilinguals’ L1 and L2 and demonstrate how early and late bilinguals organize their phonetic system(s). These findings underscore the importance of providing comparisons of bilinguals in their two languages as well as comparisons of bilinguals to monolinguals of both languages in order to adequately describe how the L1 and L2 are restructured as the L2 is learned and how bilinguals process and use their two languages.

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Appendix

Means and SDs (in parentheses) for the acoustic values (B1-B0, B2-B1) of the English vowels produced by the groups of English monolinguals and Korean-English bilinguals

| | | <i>English vowel</i> | | | | | |
|--------------|--------------|----------------------|--------------|-------------|-------------|-------------|-------------|
| <i>Group</i> | <i>Value</i> | /i/ | /ɪ/ | /u/ | /ʊ/ | /æ/ | /ɛ/ |
| E Adult | B1-B0 | 2.74 (.48) | 4.38 (.59) | 3.27 (.51) | 4.93 (.58) | 6.96 (1.02) | 5.80 (.87) |
| | B2-B1 | 10.98 (.55) | 8.31 (.50) | 4.33 (.56) | 4.81 (.72) | 4.26 (1.02) | 5.99 (.94) |
| E Child | B1-B0 | 2.70 (.62) | 4.63 (.55) | 3.94 (.37) | 5.24 (.41) | 7.43 (.36) | 6.07 (.53) |
| | B2-B1 | 11.84 (.69) | 8.62 (.38) | 6.01 (.54) | 5.23 (.57) | 5.53 (.54) | 6.64 (.55) |
| Early + 1 | B1-B0 | 3.05 (.49) | 3.96 (.45) | 4.04 (.62) | 4.51 (.59) | 6.45 (1.11) | 6.09 (1.06) |
| | B2-B1 | 11.39 (1.32) | 9.56 (.94) | 6.25 (.79) | 5.97 (.63) | 5.92 (1.05) | 6.58 (.93) |
| Early + 7 | B1-B0 | 2.04 (.87) | 3.43 (.93) | 2.77 (.75) | 4.17 (.85) | 6.16 (.81) | 5.13 (.76) |
| | B2-B1 | 11.94 (1.11) | 9.43 (.69) | 6.55 (1.36) | 5.75 (.88) | 5.99 (.94) | 7.41 (.95) |
| Late + 1 | B1-B0 | 3.08 (.68) | 3.27 (.48) | 3.08 (.49) | 3.28 (.41) | 6.14 (1.16) | 5.98 (.76) |
| | B2-B1 | 10.44 (1.28) | 10.10 (0.63) | 5.22 (.67) | 5.99 (1.01) | 6.43 (.87) | 6.02 (1.15) |
| Late + 7 | B1-B0 | 2.74 (.79) | 2.87 (.96) | 3.11 (.49) | 3.42 (.86) | 5.43 (.79) | 5.31 (.80) |
| | B2-B1 | 10.02 (.93) | 9.96 (1.00) | 6.21 (.92) | 5.74 (.59) | 6.14 (.82) | 6.42 (.67) |

Means and SDs (in parentheses) for the acoustic values (B1-B0, B2-B1) of the Korean vowels produced by the groups of Korean monolinguals and Korean-English bilinguals

| | | <i>Korean vowel</i> | | | | |
|--------------|--------------|---------------------|-------------|-------------|-------------|------------|
| <i>Group</i> | <i>Value</i> | /i/ | /ɪ/ | /u/ | /ɛ/ | /e/ |
| K Adult | B1-B0 | 2.90 (.71) | 2.65 (.93) | 2.73 (.51) | 4.18 (.60) | 4.15 (.81) |
| | B2-B1 | 10.59 (.74) | 6.21 (1.71) | 6.29 (1.18) | 8.57 (.55) | 8.38 (.59) |
| K Child | B1-B0 | 3.23 (.52) | 2.88 (1.43) | 3.47 (.97) | 4.33 (.61) | 4.43 (.89) |
| | B2-B1 | 11.13 (1.22) | 5.43 (1.93) | 5.24 (1.20) | 8.95 (.35) | 7.89 (.72) |
| Early + 1 | B1-B0 | 3.14 (0.66) | 2.88 (.41) | 3.55 (.60) | 4.57 (.57) | 4.64 (.80) |
| | B2-B1 | 10.78 (1.28) | 8.53 (1.55) | 5.79 (.94) | 8.38 (.74) | 7.93 (.88) |
| Early + 7 | B1-B0 | 2.36 (1.05) | 2.68 (.48) | 2.67 (.69) | 3.20 (1.21) | 4.15 (.72) |
| | B2-B1 | 11.11 (1.40) | 6.76 (1.48) | 6.54 (.87) | 9.59 (1.26) | 8.45 (.70) |
| Late + 1 | B1-B0 | 3.19 (.74) | 4.11 (.83) | 3.15 (.65) | 4.67 (.95) | 4.24 (.62) |
| | B2-B1 | 11.07 (.77) | 6.64 (.71) | 5.53 (1.44) | 8.59 (.39) | 8.46 (.59) |
| Late + 7 | B1-B0 | 2.56 (.80) | 2.66 (.87) | 2.93 (.44) | 4.20 (1.02) | 4.40 (.62) |
| | B2-B1 | 10.69 (1.02) | 6.75 (1.34) | 5.30 (.56) | 8.24 (.43) | 7.68 (.59) |