LANGUAGE LEARNING
A Journal of Research in Language Studies

Language Learning ISSN 0023-8333

EMPIRICAL STUDY

Age Effects in First Language Attrition: Speech Perception by Korean-English Bilinguals

Sunyoung Ahn,[a] Charles B. Chang,[b] Robert DeKeyser,[c] and Sunyoung Lee-Ellis[d]

[a]Harvard University, [b]Boston University, [c]University of Maryland, and [d]Foreign Service Institute

This study investigated how bilinguals' perception of their first language (L1) differs according to age of reduced contact with L1 after immersion in a second language (L2). Twenty-one L1 Korean-L2 English bilinguals in the United States, ranging in age of reduced contact from 3 to 15 years, and 17 control participants in Korea were tested perceptually on three L1 contrasts differing in similarity to L2 contrasts. Compared to control participants, bilinguals were less accurate on L1-specific contrasts, and their accuracy was significantly correlated with age of reduced contact, an effect most pronounced for the contrast most dissimilar to L2. These findings suggest that the earlier bilinguals are extensively exposed to L2, the less likely they are to perceive L1 sounds accurately. However, this relationship is modulated by crosslinguistic similarity, and a

This research was supported by funding from the Ph.D. Program in Second Language Acquisition at the University of Maryland. The funding source was not involved in the design of the study, in the collection, analysis, and interpretation of data, in the writing of the manuscript, or in the decision to submit the manuscript for publication. We thank Dr. Youngkyu Kim at Ewha Womans University for his substantial support and Ms. Irene Jieun Ahn (formerly at Ewha Womans University and currently at Michigan State University) for her help during data collection in Korea.

This article has been awarded Open Materials and Open Data badges. All materials and data are publicly accessible via the Open Science Framework at https://osf.io/B2478 and at https://osf.io/G4C7Z. Learn more about the Open Practices badges from the Center for Open Science: https://osf.io/tvyxz/wiki.

Correspondence concerning this article should be addressed to Charles B. Chang, Boston University, Linguistics Program, 621 Commonwealth Avenue, Boston, MA 02215. E-mail: cc@bu.edu

DOI: 10.1111/lang.12252

turning point in L2 acquisition and L1 attrition of phonology appears to occur at around age 12.

Keywords critical period; age effects; attrition; age of arrival; laryngeal contrast; perceptual assimilation

Introduction

Among the factors that contribute to the dual language proficiency of bilinguals, the age of acquisition (AOA) of the second language (L2) has been an important area of research in recent decades (DeKeyser, 2012; Kroll & de Groot, 2005). Many studies have shown that age-related maturational constraints[1] are a powerful variable in the explanation of ultimate attainment in the L2 (for reviews, see DeKeyser & Larsen-Hall, 2005; Hyltenstam & Abrahamsson, 2003), whereas only a few studies have reported age effects in the first language (L1). This literature suggests that early exposure to a L2, which results in a decrease in contact with the L1, may play a role not only in bilinguals' L2 competence but also in their L1 competence. However, the degree to which a bilingual's age of reduced contact with the L1 predicts L1 attrition remains unclear.

Given the need to understand the effects of age on L1 attrition,[2] this study investigated how L1 Korean–L2 English bilinguals' perception of L1 sounds differed according to their age of reduced contact, which corresponded in this study to their age of arrival in a L2 environment (namely, the United States). Among many terms that have been used to refer to the age coinciding with the onset of L1 attrition, such as *age of departure* (Ammerlaan, 1996) and *age of arrival* (Pelc, 2001), we opt to use the term coined by Bylund (2009), *age of reduced L1 contact*, because it expresses most clearly the crucial concept for our purposes: the age at which there is no longer a robust L1 environment.

In what follows, we review previous work that addressed the effects of AOA on both the L2 and the L1, present a theoretical framework for conceptualizing crosslinguistic perceptual similarity, and then outline specific research questions regarding age effects on the perception of three L1 Korean contrasts that differ in terms of their phonological alignment with L2 English contrasts—namely, a nasal versus lateral sonorant contrast (/n/–/l/), a lax versus tense stop contrast (/t/–/t*/), and a nontense versus tense fricative contrast (/s/–/s*/).

Background

Age Effects in L2 Acquisition

Many studies have provided evidence that early exposure to a L2 can lead to more nativelike L2 proficiency. In particular, L2 phonology seems to be relatively strongly influenced by age of L2 exposure compared to other linguistic domains (see Granena & Long, 2013). For example, Flege, Yeni-Komshian, and Liu (1999) examined the L2 English competence of 240 L1 Korean learners, whose AOA for English ranged from 3 to 15 years, in both phonology and morphosyntax. They found that AOA showed a significant relationship with L2 phonological proficiency although not with L2 morphosyntactic proficiency (cf. Johnson & Newport, 1989).

These age effects in L2 phonological acquisition have been documented in enough detail to outline the boundaries of a critical period for nativelike ultimate attainment. For instance, Guion (2005) compared 10 L1 Korean–L2 English early bilinguals (AOA of 1–6 years), 10 late bilinguals (AOA of 15–34 years), and 10 native English speakers in production and perception of English stress patterns, finding that the early bilinguals not only outperformed the late bilinguals but also showed nativelike proficiency. Likewise, in Tsukada et al. (2005), 34 L1 Korean–L2 English child bilinguals (AOA of 6–14 years) performed more similarly to native controls in both producing and perceiving L2 vowels than did 34 adult bilinguals (AOA later than 21 years). Converging evidence from MacKay, Flege, and Imai's (2006) examination of L1 Italian–L2 English bilinguals' L2 accent showed that only bilinguals whose AOA was earlier than 10 years fell into the range of native speakers. Taken together, these findings suggest that nativelike pronunciation of the L2 is not likely to be acquired after an AOA of 14 years and that the optimal window for L2 phonological acquisition might close around the age of 10, or even earlier if perception-only studies are taken into account (e.g., Pallier, Bosch, & Sebastián-Gallés, 1997; Sebastián-Gallés & Soto-Faraco, 1999).

Age Effects in L1 Attrition

Although empirical studies are increasingly providing insights into how AOA affects acquisition of L2 phonology, age effects on the L1 have rarely been investigated directly. Only recently have researchers started to examine age effects on the L1 competence of adopted or early immigrant bilinguals (Bylund, 2009; Montrul, 2008). In part, this is due to the frequent ambiguity of age effects on the L1, which can reflect attrition (i.e., loss of L1 knowledge after its successful acquisition), interrupted (or incomplete) acquisition, or both of these processes.

One body of research that bears on the study of L1 perceptual attrition in early bilinguals is the literature on L2 effects in late bilinguals, which shows that L2-influenced modifications to the phonetics and/or phonology of the L1 may occur even in learners who acquire a L2 after the age of 18 (de Leeuw, 2014; de Leeuw, Opitz, & Lubińska, 2013). For example, L1 English speakers in their 20s were found to modify several aspects of their L1 production during the first weeks of immersive L2 Korean learning (Chang, 2012, 2013b), and similar effects of L2 immersion on the acoustic properties, perceived accent, and/or phonological rule implementation of L1 production have been reported in various late-bilingual populations: L1 English–L2 Portuguese (Major, 1992), L1 Russian–L2 English (Dmitrieva, Jongman, & Sereno, 2010), L1 German–L2 English and L1 German–L2 Dutch (de Leeuw, Mennen, & Scobbie, 2012, 2013; de Leeuw, Schmid, & Mennen, 2010; Hopp & Schmid, 2013; Schmid & Hopp, 2014), and L1 Dutch–L2 English (Mayr, Price, & Mennen, 2012). Effects of L2 immersion have also been observed in L1 perception, in L1 Spanish–L2 English and L1 English–L2 French late bilinguals (Mazzaro, Cuza, & Colantoni, 2016; Tice & Woodley, 2012).

Although the literature on L2 effects in late bilinguals has provided evidence of L1 malleability, it has not focused on age effects on the L1 per se, whereas other research has been specifically concerned with age effects. Some researchers have investigated age effects on the L1 through the lens of relearning, showing that bilinguals' early experiences with the L1 (i.e., during childhood), even after drastically reduced exposure, can help them (re)learn it to a higher level compared to typical late-onset L2 learners. For instance, Au, Oh, Knightly, Jun, and Romo (2008) examined L1 Spanish–L2 English early bilinguals' phonological and morphosyntactic competence in the L1, which they had not used after immigrating to the United States until they started to relearn it in college. In this study, the bilinguals with early experience overhearing Spanish (until age 6) showed a more nativelike accent in the L2 than late L2 learners. In addition, when their early overhearing experience was coupled with experience speaking (until age 7), they performed at a more nativelike level than late L2 learners not only in speech production but also in grammar.

Positive effects of continued L1 experience in childhood for language maintenance were also found by Knightly, Jun, Oh, and Au (2003). They compared L1 Spanish–L2 English early bilinguals and late L2 learners of Spanish to native Spanish speakers. The early bilinguals, who had overheard the L1 until age 12 and relearned it in college, patterned more similarly to the native speakers than did the late learners of Spanish (AOA after age 10) in phonological measures although not in morphosyntactic measures. Similarly, Oh, Jun, Knightly, and

Au (2003) demonstrated that the effects of early L1 experience can be enhanced by relearning, even with minimal use of the L1 following the onset of extensive L2 exposure.[3] In their study, the early bilinguals, who had overheard and often spoken the L1 (Korean) until age 7 and then relearned the L1 in college, not only outperformed late L2 learners but also patterned like native speakers in perception and production of L1-specific consonant contrasts. This result implies that, as long as early bilinguals regularly use the L1 up to a certain age, their L1 phonological competence can reach a nativelike level upon relearning even despite a drastic reduction in contact with the L1.

The aforementioned studies have shown more robust age effects on L1 phonology than on other L1 domains, as is the case in L2 acquisition. To be specific, early bilinguals' L1 phonology appears to be maintained at, or regained up to, a nativelike level more successfully than other aspects of the L1 (i.e., morphosyntax). However, although these studies have provided suggestive evidence for the sensitivity of L1 phonology to age of reduced contact, they did not directly address the question of age effects on bilinguals' L1 phonology. This is because these studies were concerned with age effects on *relearning* the L1, not on losing the L1. That is, because these studies examined the effects of early L1 experience on L1 competence after relearning, it is difficult to determine whether the observed L1 features had actually deteriorated before the reexposure involved in relearning.

Two studies investigating remnants of the L1 in international Korean adoptees have provided additional data relevant to the question of age effects in L1 attrition. More specifically, Ventureyra, Pallier, and Yoo (2004) and Hyltenstam, Bylund, Abrahamsson, and Park (2009) found many cases of L1 perceptual loss in their adoptee participants (adopted to France and Sweden, respectively), regardless of relearning. In both studies, the adoptees showed a range in age of adoption (3 to 9 years in Ventureyra et al., 2004; birth to 10 years in Hyltenstam et al., 2009) and, following adoption, were mostly cut off from L1 exposure for many years. The adoptees in Hyltenstam et al., however, had later (around 3 years prior to the time of study on average) engaged in relearning the L1 for a period of at least one university semester, whereas the adoptees in Ventureyra et al. comprised two groups: one with some degree of L1 reexposure due to travel to Korea and one with no L1 reexposure. The adoptees in Ventureyra et al. performed as poorly in L1 perception tasks and as well in L2 perception tasks as naïve native speakers of their L2 (French), with few differences between the two groups of adoptees. In other words, the adoptees patterned as if they had never been exposed to their L1. By comparison, the majority of adoptees in Hyltenstam et al., even after a period of L1 relearning, patterned in a similar manner, showing no L1 perceptual advantage over native Swedish late learners of Korean. Nevertheless, there were several adoptees (7 out of 21) who outperformed the native Swedish group. Individual variation in L1 relearning was also observed in Bowers, Mattys, and Gage (2009), who found that English speakers with previous (but unremembered) exposure to Hindi or Zulu showed a perceptual advantage over English controls following discrimination training on L1-specific contrasts, but only when they were under age 40 at the time of testing.

Two aspects of these findings provide important insights for L1 attrition research. First, in Hyltenstam et al. (2009), two late adoptees showed an apparent effect of early L1 (Korean) exposure on L1 relearning. These participants, adopted at ages 9 and 10 to Sweden, had the latest ages of adoption in the study and also showed the best performance in the L1 perceptual task. Moreover, although they outperformed native Swedish late learners of Korean in perception, they did not do so in grammar. Together with the profound L1 loss observed among most of the participants who were adopted earlier in life, this result implies that the later L1 exposure ends, the less L1 attrition occurs. Furthermore, phonology appears to be less vulnerable to attrition than other domains. Second, Ventureyra et al. (2004) found that the capacity of Korean adoptees in France to distinguish L1 Korean phonemes depended on the difficulty of the contrasts. These adoptees failed to discriminate Korean voiceless consonant contrasts, which are difficult for native French speakers to perceive, whereas they successfully distinguished Korean vowel contrasts, which are easy for native French speakers to perceive. This result suggested that the degree of observed L1 attrition may depend on the perceptual difficulty of the tested L1 features vis-à-vis the L2. However, it should be noted that the populations examined in these two studies were sufficiently unusual that the results cannot be generalized to typical bilinguals. In particular, the language environment of adoptees postadoption is fundamentally different from that of typical early bilinguals. Whereas typical early bilinguals tend to receive continuous exposure to the L1 during childhood (at least at home, and often from their parents), adoptees are rarely exposed to the L1 after adoption because even their parents speak to them in the L2.

The production abilities of typical bilinguals evincing a range of developmental profiles was explored in Yeni-Komshian, Flege, and Liu's (2000) study of 240 L1 Korean–L2 English bilinguals with AOAs for the L2 between 1 and 23 years. In this project, the largest published study examining bilinguals' speech production in both of their languages, samples of L1 and L2 pronunciation were elicited through a delayed sentence repetition task and then rated by native speakers of each language on a 9-point scale. The results showed that bilinguals who acquired the L2 after age 12 maintained the L1, but not the L2, at a nativelike level, while those who acquired the L2 before age 5 showed nativelike pronunciation of the L2 but a distinct foreign accent in the L1. Although the L1 ability of the participants in this study was confounded with their relative L2 proficiency, the results suggested that robust L1 exposure up to age 12 augurs well for the maintenance of the L1 at a nativelike level. Table 1 summarizes the findings of the L1 attrition studies discussed above and their limitations.

Crosslinguistic Similarity and Perceptual Assimilation

An important finding by Ventureyra et al. (2004) is that L1 contrasts vary in terms of their vulnerability to attrition. In particular, L1 contrasts that are not found in the dominant language (L2) appear to be more susceptible to loss than those that are similar to contrasts found in the dominant language. To put it a different way, the availability of phonological support from a L2 contrast may serve to mitigate the risk of L1 attrition. Thus, in the case of Ventureyra et al.'s Korean–French bilinguals, the Korean laryngeal contrasts among lax, tense, and aspirated voiceless obstruent phonemes were lost, as the relevant phonological feature of tenseness is not found in French. In contrast, the Korean vowel quality contrasts among the /i/, /a/, and /u/ phonemes were not lost, as the distinguishing features of vowel height, backness, and rounding are in fact found in French (such that French contains similar vowels in its phonemic inventory).

The role of crosslinguistic similarity in influencing bilingual speech perception was elaborated in detail by Best and Tyler (2007) in an influential theory called the Perceptual Assimilation Model-L2 (PAM-L2). The basic tenet of PAM-L2 is that discrimination of L2 phonological contrasts follows from the way in which members of the contrast are perceptually assimilated to (i.e., perceived in terms of) L1 phonemes. Besides the possibility of no assimilation (of one or both members of the contrast), there are three main types of perceptual assimilation. First, the two L2 phonemes may be assimilated to different L1 phonemes (two-category assimilation), in which case discrimination is good. Second, the two L2 phonemes may be assimilated to the same L1 phoneme equally well (single-category assimilation), in which case discrimination is poor. Finally, the two L2 phonemes may be assimilated to the same L1 phoneme, but with a difference in goodness of fit (category-goodness assimilation), in which case discrimination is of an intermediate level.

Table 1 Summary of studies reporting age effects on L1 perception and/or production

Study	L1 aspect(s)	Participants	Findings	Limitations
Au et al. (2008)	L1 (Spanish): pronunciation, morphosyntax	30 Spanish-English bilinguals (ARC $<$ 7), 25 Spanish NSs, 39 English late learners of Spanish	Pronunciation: NSs $>$ bilinguals $>$ late learners; morphosyntax: NSs $>$ bilinguals $\approx$ late learners	Different focus: L1 recovery as opposed to attrition
Knightly et al. (2003)	L1 (Spanish): pronunciation, morphosyntax	15 Spanish-English bilinguals (ARC $<$ 12), 15 Spanish NSs, 15 English late learners of Spanish	Pronunciation: NSs $\geq$ bilinguals $>$ late learners; morphosyntax: NSs $>$ bilinguals $\approx$ late learners	
Oh et al. (2003)	L1 (Korean): perception, pronunciation	21 Korean-English bilinguals (ARC $<$ 7), 12 Korean NSs, 10 English late learners of Korean	Perception: NSs $>$ bilinguals $>$ late learners; pronunciation: NSs $>$ bilinguals $>$ late learners	

(*Continued*)

Table 1 Continued

Study	L1 aspect(s)	Participants	Findings	Limitations
Hyltenstam et al. (2009)	L1 (Korean): perception, morphosyntax	21 Korean-Swedish bilinguals (ARC $<$ 10), 11 Swedish NSs, 3 Korean NSs	Perception: Korean NSs $>$ bilinguals (adoptees) $\approx$ Swedish NSs; morphosyntax: Korean NSs $>$ Swedish NSs $>$ bilinguals (adoptees)	Unusual case of bilinguals (adoptees)
Ventureyra et al. (2004)	L1 (Korean): perception	18 Korean-French bilinguals (ARC 3–9), 12 French NSs, 12 Korean NSs	Korean NSs $>$ bilinguals (adoptees) $\approx$ Swedish NSs	
Yeni-Komshian et al. (2000)	L1 (Korean) and L2 (English): pronunciation	240 Korean-English bilinguals (ARC 1–23), 24 Korean NSs, 24 English NSs	Korean: Korean NSs $\approx$ bilinguals (ARC $>$12); English: English NSs $>$ bilinguals (ARC 1–5)	L1 attrition confounded with L2 proficiency

Note. ARC = age of reduced contact, NSs = native speakers.

Although PAM-L2 was originally formulated to explain perception of L2 contrasts, the core insight of the theory—that discrimination outcomes follow from crosslinguistic perceptual similarity—is also applicable to the perception of L1 contrasts that may be undergoing attrition due to the influence of a dominant L2. Thus, the results of Ventureyra et al. (2004) are amenable to an explanation in terms of two-category versus single-category/category-goodness assimilation. For French-dominant bilinguals, the L1 Korean vowel contrasts are perceptually easy because they are mapped to distinct L2 vowels, whereas the L1 Korean consonant contrasts are perceptually difficult because they are mapped to the same L2 consonant (e.g., Korean lax /t/ and aspirated /t^h/ are both associated perceptually with French /t/).

The Current Study

Given the various limitations of the literature addressing age effects in L1 attrition, further investigation of a critical period for L1 attrition is needed. The limitations of previous findings are threefold: (a) a different focus (L1 reacquisition), (b) an atypical population (adoptees), and (c) an empirical confound (with relative L2 proficiency). It remains unclear when and how L1 attrition occurs as a function of AOA for the L2 or, alternatively, age of reduced contact with the L1. Thus, our first research question in this study was whether age of reduced contact is a significant predictor of bilinguals' ability to perceive L1 speech sounds in a L2 environment and, if so, what age marks the end of a critical period for L1 attrition in perception. In investigating this question, the current study addressed each of the limitations described above by focusing on L1 attrition, examining the more common case of immigrant bilinguals, and accounting for relative use of the L1 versus L2. In particular, we examined the case of L1 Korean–L2 English bilinguals in the United States.

Following from the disparity in vulnerability of L1 contrasts observed in the literature, our second research question was whether the role of age of reduced contact in L1 perceptual maintenance would be modulated by crosslinguistic perceptual assimilability. To address this question, we examined a range of phonemic contrasts in Korean: the nontense versus tense fricative contrast (/s/–/s*/),[4] the lax versus tense plosive contrast (/t/–/t*/), and the nasal versus lateral contrast (/n/–/l/). These contrasts were selected for two main reasons: (a) their overall similarity in terms of being consonants articulated around the alveolar region and (b) their differences with respect to perceptual assimilability to English contrasts. Because the lax/nontense versus tense distinction exists in Korean but not in English, contrasts based on this feature are phonologically specific to the L1 and, therefore, provide the clearest indication of L1 attrition, not being easily assimilated to L2 contrasts. In particular, the /s/–/s*/ contrast is known to be difficult to discriminate for heritage Korean speakers born in the Unites States (Lee-Ellis, Idsardi, & Phillips, 2009). Among the four Korean tenseness contrasts besides /s/–/s*/, the /t/–/t*/ contrast is articulated the most similarly to /s/–/s*/, at a dentialveolar location with the tip of the tongue. Finally, /n/–/l/ was chosen as the easy L1 contrast because this contrast is articulated at the same general place as the other two contrasts, and the nasal versus lateral distinction exists in both the L1 and the L2. Consequently, we predicted that both the control group (L1 Korean speakers in Korea) and the experimental group (L1 Korean speakers in the United States) would discriminate between these sounds because they constitute a two-category contrast vis-à-vis the L2.

Regarding the two tenseness contrasts (/t/–/t*/, /s/–/s*/), which can both be distinguished from /n/–/l/ as less assimilable to a L2 contrast because they rely on a feature that is absent from the L2, crosslinguistic perceptual data from native English listeners (Schmidt, 2007) motivate further distinguishing these two contrasts from each other. When asked to label Korean sounds in terms of English sounds and rate their goodness as exemplars of those English sounds, English listeners identified (nonpalatalized) Korean /s/ and /s*/ with the same English sound (/s/) consistently, at rates of 88 to 96%. Both sounds, moreover, were given relatively high goodness ratings, which differed from each other on average by less than 0.7 on a 5-point scale. In other words, the /s/–/s*/ contrast can be considered a single-category contrast. On the other hand, Korean /t/ and /t*/ were not consistently identified with the same English sound; rather, they tended to be identified with different English sounds (namely, /t/ and /d/), although somewhat less consistently (at rates of 85 to 90%) and, in the case of /t*/, with a greater spread of alternative responses. In addition, both /t/ and /t*/ were given lower goodness ratings (mean 3.8 and 3.9, respectively) than /n/ (mean 4.2) on the same 5-point scale. These data suggested that the /t/–/t*/ contrast is not exactly a category-goodness contrast but is not a canonical two-category contrast either. Rather, it may be considered to be somewhere in between these two types.

This classification of L1 contrasts in terms of assimilability to the L2, along with the previous findings on age effects in L1 attrition, led to three predictions regarding the role of age of reduced contact in L1 perceptual attrition. First, under the assumption that bilinguals immersed in a L2 environment would show signs of L1 perceptual attrition in comparison to native speakers in a L1 environment, we predicted that age of reduced contact would be a significant predictor of bilinguals' L1 perceptual ability after accounting for other relevant factors (and potential covariates) such as L1 use and exposure, L1 proficiency, and L1 education (e.g., see Hakuta & D'Andrea, 1992). Second, we predicted that the effect of age of reduced contact would differ across L1 contrasts according to the assimilability of the L1 contrast to the L2. Thus, we expected age of reduced contact to show little to no effect in the case of /n/–/l/ (a two-category contrast), but a significant effect in the case of /t/–/t*/ (somewhere between a category-goodness and two-category contrast) and an even stronger effect in the case of /s/–/s*/ (a single-category contrast). Third, given the results of Yeni-Komshian et al. (2000), we predicted that a turning point in maintenance of nativelike L1 perception would occur at around age 12. These three predictions were tested in a Korean perception experiment that directly compared native Korean listeners in Korea with Korean–English bilinguals in the United States evincing a wide range of ages of reduced contact.

Method

Participants

Twenty-one L1 Korean–L2 English bilinguals (16 female, $M_{\text{age}} = 26.8$ years, $SD = 7.8$), who had immigrated to the United States from the Republic of Korea (South Korea), were recruited from the Greater Washington, DC, area through flyers and personal contacts. They were paid $10 per hour for their participation. To be eligible, a bilingual's age of arrival, which corresponds to the age of reduced contact with the L1, had to be between 3 and 15 years.[5] The mean age of reduced contact in the bilingual group was 9.5 years ($SD = 3.4$). Consistent with their long-term (and current) residence in a L2 environment, the majority (12/21) of these bilinguals reported being dominant in the L2 (English) at the time of study.

To account for interspeaker variation in L1 experience, overall lifetime ratios of L1 to L2 exposure (relative L1 exposure) as well as use (relative L1 use) were calculated for all the bilinguals based on their self-reported exposure to, and use of, Korean and English during specific age blocks.[6] These blocks were delimited by school entrance ages and ranged from birth to the current age: (a) birth to age 4, (b) age 5 to 12, (c) age 13 to 18, and (d) age 19 and older. For instance, one bilingual reported that he used Korean 100% of the time for two age blocks (birth to age 4, age 5 to 12), but Korean and English each 50% of the time for the other two age blocks (age 13 to 18 and age 19 and older). Therefore, his accumulated language use (in terms of percentages) across the four age blocks was 300 (100 + 100 + 50 + 50) for Korean versus 100 (0 + 0 + 50 + 50) for English, resulting in a value for relative L1 use of 3 (300/100). The construct of L1 experience was operationalized in this way (i.e., as relative to L2 experience) so that it would be less confounded with age of reduced contact.[7] The results of these ratio calculations showed that the means for relative L1 exposure and relative L1 use were, respectively, 1.8 ($SD = 1.2$) and 2.1 ($SD = 1.5$).

Because most bilinguals were of an age that meant they had attended school in Korea before moving to the United States, information about their previous formal education in Korean was collected and used to calculate a total amount of education in Korean (see below). On average, L1 education was substantial ($M = 22.0$ months, $SD = 22.8$), but varied considerably across the bilinguals, even when their age of arrival in the United States was similar. For instance, one bilingual who had arrived at age 6 had received minimal education in Korean (less than a week total), while another who had arrived at age 7 had received more than 18 months. Along with their experience with Korean, the bilinguals' listening comprehension in Korean (L1 listening proficiency) was measured using a standardized proficiency test (see below). The scores on this test revealed that L1 listening proficiency for these bilinguals was generally high ($M = 86.2$ out of 100, $SD = 12.8$).

To serve as a control group, 17 age-matched native Korean speakers (14 female, $M_{age} = 26.8$ years, $SD = 7.6$) were recruited in Seoul. Given the compulsory nature of English education in modern Korea, all Korean control participants had knowledge of English as an additional language. Their self-rated English reading ability was substantial ($M = 6.4$ out of 10, $SD = 2.0$), although their self-rated English spoken proficiency was low ($M = 4.6$ out of 10, $SD = 1.7$). To be eligible to participate, Korean controls had to have not lived in an English-speaking country for more than 6 months before age 19. For the purposes of comparison with the bilinguals in the United States, the Korean controls' Korean listening proficiency was measured with the same test, and most received perfect scores ($M = 98.0$ out of 100, $SD = 1.9$).

Stimuli

The stimuli for the perception task comprised three contrasts between coronal consonants of Korean: the nontense versus tense fricative contrast (/s/–/s*/), the lax versus tense plosive contrast (/t/–/t*/), and the nasal versus lateral contrast (/n/–/l/). To construct the experimental items, these Korean consonants were embedded in nonce words, in the initial position of the frame [_ak^{h}a], as shown in Table 2.

A disyllabic frame for the stimuli was chosen to impose a demand on working memory, thus encouraging participants to use long-term phonological representations, instead of detailed acoustic memory traces, to complete the task. That is, the increased working memory load of listening to longer stimuli

Table 2 Test stimuli (minimal pairs) according to predicted perceptual difficulty

Minimal pair		Predicted perceptual difficulty
나카-라카	/nak^{h}a/–/lak^{h}a/	least difficult
다카-따카	/tak^{h}a/–/t*ak^{h}a/	more difficult
사카-싸카	/sak^{h}a/–/s*ak^{h}a/	most difficult

was intended to prevent any participants without a robust mental representation of the target phonemes (i.e., phonological competence) from being able to perform the task based purely on low-level acoustic differences (and, thus, misrepresent themselves as having high phonological competence). The three minimal pairs shown in Table 2 were recorded by six native Korean speakers (three females) 10 times each, for a total of 60 recordings of each item. In the perception task, the sequence of stimuli in each trial was constructed by selecting tokens randomly from among the 120 recordings for the contrast being tested on that trial.

Procedure

Language Background Questionnaire

After giving informed consent, participants completed a language background questionnaire, which collected information on their language experience and residence history. Given that language experience is a potentially crucial factor for explaining L1 attrition, one of the challenges for a L1 attrition study is to operationalize this factor precisely. To this end, this study used a language background questionnaire specifically developed by Lee-Ellis (2012) to measure heritage speakers' language use and exposure in each of several periods of their life (e.g., kindergarten, elementary school, middle school, etc.) rather than as a global estimate over the lifespan. The questionnaire was in a spreadsheet format and took about 10 to 20 minutes to complete (for the full questionnaire, see Lee-Ellis, 2012, pp. 191–200). Participants entered data about each kind of experience (e.g., formal instruction in Korean) in individual cells asking about age of onset, intensity (hours per week), and total duration (months). On the basis of these figures, a total amount of L1 experience was then calculated automatically.

Listening Proficiency Test

Participants' Korean listening proficiency was measured using the Intermediate A section of the 18th Test of Proficiency in Korean (TOPIK), an intermediate-level listening comprehension test (Korea Institute for Curriculum and

Evaluation, 2010). This test consisted of 30 multiple-choice items with a maximum possible score of 100 (for reference, a score of 70 is usually the minimum for Korean college admission).

Speeded Sequence Recall Task

To measure participants' capacity to discriminate Korean phonemes, a speeded sequence recall task was employed. This task presented each target contrast in sequences of four nonce words, following the procedures in Dupoux, Sebastián-Gallés, Navarrete, and Peperkamp (2008) and Lee-Ellis et al. (2009), with a shorter interstimulus interval. A relatively short interstimulus interval (150 milliseconds) was used to make the task more challenging and to encourage phonological-level processing (e.g., see Lee-Ellis, 2012). We used this task rather than other possible tasks (e.g., an AX discrimination task) because sequence recall involves a higher memory demand, requiring the encoding of several items in a sequence. As with the short interstimulus interval, this memory demand was designed to encourage participants to process the stimuli at a phonological level (Dupoux et al., 2008; Lee-Ellis et al., 2009).

The sequence recall experiment was conducted in E-Prime and consisted of two phases: an introduction phase and a test phase. In the introduction phase, participants were familiarized with the task by learning the association between a number key and one member of each minimal pair. Thus, when they pressed 1 on the keyboard, they heard six different voices saying one member of the given pair (e.g., /sak^{h}a/). When they pressed 2, they heard six different voices saying the other member of the pair (e.g., /s*ak^{h}a/). Participants could hear each token set as many times as they wanted before moving on to the next member of the pair. After hearing all tokens of all pairs, they clicked a button marked *Go to the next step* to move on to the test phase.

The test phase consisted of two sessions, a practice session and a main test session, which were blocked by contrast, such that all trials were completed for one contrast before moving on to the next contrast (with the order of the contrasts randomized across participants). In the practice session, each trial presented a two-item sequence for the given minimal pair. For example, in the case of /sak^{h}a/–/s*ak^{h}a/, if participants thought that they had heard the sequence /sak^{h}a/–/s*ak^{h}a/, they had to press 1 and 2 in that order; if they thought that they had heard /sak^{h}a/–/sak^{h}a/, they had to press 1 and then 1 again. To prevent the use of echoic memory, participants had to wait for a response signal (presented 150 milliseconds after the final stimulus) before responding. After a response was entered, immediate feedback was provided on accuracy. Participants were able to practice as much as they wanted and indicated that they were ready to begin the main test by clicking a button. In the main test session, each trial presented a four-item sequence for the given pair. For example, if participants thought that they had heard the sequence /sak^{h}a/–/s*ak^{h}a/–/sak^{h}a/–/s*ak^{h}a/, they had to press 1, 2, 1, and 2 (in that order) after receiving the response signal. In this session, no feedback was provided on accuracy. A total of 28 trials were randomly presented for each contrast, for a grand total of 84 (28 $\times$ 3) test trials.

Statistical Analysis

Responses on test trials were scored as accurate when all four key presses were correct and as inaccurate otherwise. The likelihood of an accurate response in the test session was then modeled using mixed-effects logistic regression (see Jaeger, 2008, for arguments in favor of this type of analysis of categorical outcomes over parametric analysis on percentage measures). To maximize the stability and generalizability of the models, we followed a four-stage modeling process consisting of initial exploration of potential predictors and incremental model building (with model comparisons conducted via likelihood-ratio tests), resulting in four final models (summarized in Table 3).

In the first stage of modeling, we examined a series of models built for the bilinguals' data with single fixed-effect predictors to get a sense of the informativeness of each fixed effect on its own. The random-effects structure in each of these models comprised intercepts by participant, the specific sequence of auditory stimuli presented on a given trial (stimulus sequence), and the specific sequence of keys that comprised the target response (key sequence, such as 1, 2, 1, 2). A total of 10 fixed effects were explored in this manner: the bilinguals' gender, age at testing, dominant language, age of reduced contact, length of residence in the United States, TOPIK score (L1 listening proficiency), amount of education in Korean (L1 education), lifetime ratios of L1 versus L2 exposure (relative L1 exposure) and use (relative L1 use), and experimental block. Comparison of each single-predictor model with the base (random effects only) model suggested that only one fixed effect significantly improved upon the base model—age of reduced contact, $\chi^2(1) = 9.499$, $p = .002$. Consequently, none of the noncritical predictors was carried forward to the third stage of modeling (described below).

In the second stage of modeling, we built a global model over the entire data set (Model 1) to compare the two groups (Korean controls and bilinguals) with each other. Model 1 contained dummy-coded fixed effects for group (reference level = Korean controls), contrast (reference level = /n/–/l/), and a group $\times$ contrast interaction, as well as the same random-effects structure used

Table 3 Structure of the four logistic mixed-effects regression models

Model	Data	Random effects	Fixed effects (coding / range)
1	All groups, all contrasts	Random intercepts by: participant, stimulus sequence, key sequence	Group (dummy coding; reference = controls); contrast (dummy coding, reference = /n/–/l/); group × contrast
2A	Bilingual group, all contrasts	Random intercepts by: stimulus sequence, key sequence	Relative L1 use (0.34–5.45); relative L1 exposure (0.39–4.71); L1 education (0.22–82.88 months); L1 listening proficiency (52–100 points); ARC (3–15 years); contrast (dummy coding, reference = /n/–/l/); ARC × contrast
2B	Bilingual group, tenseness contrasts	Random intercepts by: stimulus sequence, key sequence	Relative L1 use (0.34–5.45); relative L1 exposure (0.39–4.71); L1 education (0.22–82.88 months); L1 listening proficiency (52–100 points); ARC (3–15 years); contrast (dummy coding, reference = /t/–/t*/); ARC × contrast
2C	Bilingual group, /s/–/s*/ contrast	Random intercepts by: stimulus sequence, key sequence	Relative L1 use (0.34–5.45); relative L1 exposure (0.39–4.71); L1 education (0.22–82.88 months); L1 listening proficiency (52–100 points); ARC (3–15 years)

Note. ARC = age of reduced contact.

in the first stage of modeling (namely, random intercepts by participant, stimulus sequence, and key sequence). A more complex random-effects structure (e.g., including by-participant random slopes) was not used—either in this model or in any of the other final models—because models containing more complex random structures either failed to converge or showed signs of overparameterization (e.g., perfect correlation between two random effects) and/or less stable fit (e.g., singular convergence).

In the third stage of modeling, we built a model over the data set for the bilingual group only (Model 2A). The base model contained random intercepts by stimulus sequence and key sequence (but not by participant, as many of the age of reduced contact levels were exemplified by only one participant) and seven fixed effects for critical background variables: relative L1 use, relative L1 exposure, L1 education, L1 listening proficiency, age of reduced contact, contrast, and age of reduced contact × contrast. Besides the age of reduced contact × contrast interaction, all other possible interactions among fixed effects were tested by adding them to the base model one at a time and comparing models with and without the given interaction term. These model comparisons revealed that no additional interactions significantly improved upon the base model. Thus, Model 2A corresponded to the initial base model containing only the age of reduced contact × contrast interaction.

In the fourth stage of modeling, we constructed two follow-up models to Model 2A to examine effects not evident in this model's output. The first follow-up model (Model 2B) had the same random- and fixed-effects structure as Model 2A but was built only on the data for the tenseness contrasts (i.e., /t/–/t*/, /s/–/s*/) to allow for a direct comparison between these two contrasts. The second follow-up model (Model 2C) was meant to examine the effects of background predictors in the case of /s/–/s*/ specifically. Therefore, it was built only using the data for /s/–/s*/, with the same random- and fixed-effects structure as Model 2A except without the contrast or age of reduced contact × contrast terms.

Results

Outlier Tests

In order to confirm that the perception task and auditory stimuli were sound, the data for each of the three contrasts and each of the two groups were checked for outliers (an abundance of which would have suggested that there was a problem with the task or stimuli rather than merely wide variation in participants' scores). Outliers were identified by converting participants' percent accuracies for each combination of group and contrast into *z* scores and applying the

Table 4 Output of Model 1 over all groups and contrasts (with random intercepts for participant, stimulus sequence, and key sequence)

Predictor	β	SE	z	p
(Intercept)	1.167	0.270	4.319	< .001
Group: bilinguals	0.651	0.341	1.913	.056
Contrast: /t/–/t*/	–0.229	0.189	–1.212	.225
Contrast: /s/–/s*/	0.806	0.206	3.903	< .001
Group: bilinguals × contrast /t/–/t*/	–1.593	0.215	–7.428	< .001
Group: bilinguals × contrast /s/–/s*/	–1.897	0.230	–8.263	< .001

two-standard-deviation criterion for outliers. Using this method, three outliers were identified: one bilingual on /n/–/l/ (z score = –2.94), one Korean control on /t/–/t*/ (z score = –2.17), and another Korean control on /s/–/s*/ (z score = –2.32). The fact that there were only three outlier data points among 114 observations suggested that these three data points were indeed outliers rather than a reflection of any problem with the experiment itself. Therefore, they were excluded from the group range comparisons described below (but not from the regression analyses, because removing them from the regression models made no difference in the results).

Regression Analyses

As described above, mixed-effects logistic regression analyses were conducted to examine whether age of reduced contact predicted a bilingual's ability to perceive L1 speech sounds. Although the fixed and random effects varied across the four models described below (see Table 3), in each case the dependent variable was the likelihood of accuracy in the speeded sequence recall task. The output of each of these models is reported separately in Tables 4–7. However, because drawing conclusions about a contrast often requires considering the output of more than one model, below we discuss the regression results by contrast rather than by model.

Contrast 1 (Assimilable to a L2 Contrast): /n/–/l/

As expected, both bilinguals and Korean controls showed high accuracy on the /n/–/l/ contrast, reaching over 70% on average (bilinguals = 81%, Korean controls = 73%). These accuracy levels represented much better than chance-level performance (which corresponded to 1/2 × 1/2 × 1/2 × 1/2 = 6% accuracy). Importantly, the high accuracy on this contrast across groups provided evidence that both groups were able to complete the speeded sequence recall task

Table 5 Output of Model 2A over all contrasts within the bilingual group (with random intercepts for stimulus sequence and key sequence)

Predictor	β	*SE*	*z*	*p*
(Intercept)	1.978	0.514	3.851	< .001
Relative L1 use	0.079	0.060	1.318	.187
Relative L1 exposure	–0.162	0.078	–2.064	.039
L1 education (months)	0.019	0.003	5.492	< .001
L1 listening proficiency (points)	–0.004	0.006	–0.779	.436
ARC (years)	–0.040	0.034	–1.163	.245
Contrast: /t/–/t*/	–3.352	0.420	–7.984	< .001
Contrast: /s/–/s*/	–3.818	0.432	–8.843	< .001
ARC × contrast /t/–/t*/	0.193	0.041	4.742	< .001
ARC × contrast /s/–/s*/	0.320	0.044	7.300	< .001

Note. ARC = age of reduced contact.

Table 6 Output of Model 2B over the tenseness contrasts (/t/–/t*/, /s/–/s*/) within the bilingual group (with random intercepts for stimulus sequence and key sequence)

Predictor	β	*SE*	*z*	*p*
(Intercept)	–0.995	0.551	–1.805	.071
Relative L1 use	0.092	0.070	1.301	.193
Relative L1 exposure	–0.011	0.094	–0.113	.910
L1 education (months)	0.020	0.004	5.156	< .001
L1 listening proficiency (points)	–0.010	0.007	–1.537	.124
ARC (years)	0.132	0.032	4.052	< .001
Contrast: /s/–/s*/	–0.503	0.409	–1.228	.219
ARC × contrast /s/–/s*/	0.133	0.042	3.186	.001

Note. ARC = age of reduced contact.

Table 7 Output of Model 2C over the /s/–/s*/ contrast within the bilingual group (with random intercepts for stimulus sequence and key sequence)

Predictor	β	*SE*	*z*	*p*
(Intercept)	–2.739	0.772	–3.548	< .001
Relative L1 use	–0.119	0.101	–1.185	.236
Relative L1 exposure	0.241	0.140	1.718	.086
L1 education (months)	0.017	0.006	2.891	.004
L1 listening proficiency (points)	0.006	0.010	0.632	.527
ARC (years)	0.252	0.041	6.107	< .001

Note. ARC = age of reduced contact.

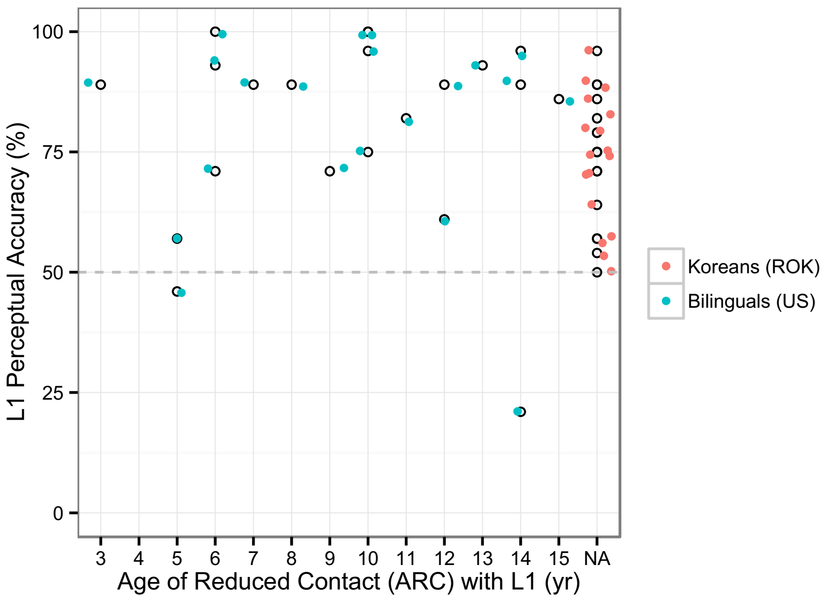

Figure 1 Accuracy for the /n/–/l/ contrast, by age of reduced contact and group. Jittered points (in filled circles) are plotted over each combination of age of reduced contact and accuracy level contained in the dataset (in hollow circles) to show the number of data points represented by each hollow circle. The dotted line marks the bottom of the accuracy range for Korean controls (excluding outliers). [Color figure can be viewed at wileyonlinelibrary.com]

without a problem, supporting the validity of accuracy comparisons on the other contrasts within this task.

The results of Model 1 (Table 4) showed that, in comparison to Korean controls' likelihood of accuracy on /n/–/l/ (represented by the intercept), bilinguals' likelihood of accuracy was not significantly different, $\beta = 0.651$, $z = 1.913$, $p > .05$. This outcome was consistent with our predictions. Because a nasal versus lateral distinction exists in both English and Korean, there was little difficulty discriminating this contrast for either group, regardless of when a bilingual's contact with Korean began to be reduced.

Accuracy on /n/–/l/ is plotted by participant as a function of age of reduced contact in Figure 1. The horizontal reference line indicates the minimum score of Korean controls (i.e., 50%). Except for one bilingual whose accuracy (at 46%) is slightly below the line (as well as the outlier with an age of reduced contact of 14), it can be seen that bilinguals are all located above the line. Additionally, the results of Model 2A (Table 5) showed no effect of age of reduced contact on bilinguals' likelihood of accuracy for /n/–/l/, $\beta = 0.006$, $z = 0.180$, $p > .05$. Thus, these findings supported the conclusion that bilinguals were overall just as accurate as Korean controls on the /n/–/l/ contrast, with no effect of age of reduced contact on performance.

Regarding the critical background predictors for bilinguals, the results of Model 2A showed no effect of relative L1 use or L1 listening proficiency, $|\beta| < 0.080$, $|z| < 1.319$, $p > .05$, but a significant effect of L1 education and relative L1 exposure. In particular, there was a positive effect of L1 education, $\beta = 0.019$, $z < 5.492$, $p < .001$, but a negative effect of relative L1 exposure, $\beta = –0.162$, $z = –2.064$, $p = .039$. These effects may have been due, on the one hand, to the reinforcing effect of learning different orthographic representations for /n/ and /l/ in school and, on the other hand, to the muddling effect of hearing either [n] or [l] in the realization of certain /l/-initial lexical items (see below for further discussion).

Contrast 2 (Less Assimilable to a L2 Contrast): /t/–/t*/

Whereas bilinguals did not differ from Korean controls in achieving high accuracy on the /n/–/l/ contrast, only the Korean control group showed a similarly high level of accuracy (70%) on the /t/–/t*/ contrast. Overall accuracy in the bilingual group was considerably lower (50%). The results of Model 1 (Table 4) showed that, whereas Korean controls' likelihood of accuracy showed no significant difference on /t/–/t*/ compared to /n/–/l/, $\beta = –0.229$, $z = –1.212$, $p > .05$, bilinguals' likelihood of accuracy showed a significant decrement on /t/–/t*/ compared to /n/–/l/, $\beta = –1.593$, $z = –7.428$, $p < .001$.

Unlike the case of /n/–/l/, where no effect of age of reduced contact was observed, the /t/–/t*/ contrast showed (in Model 2B, see Table 6) a significant effect of age of reduced contact on bilinguals' likelihood of accuracy, $\beta = 0.132$, $z = 4.052$, $p < .001$. The later a bilingual's age of reduced contact, the more likely s/he was to be accurate on this L1-specific contrast. This result was consistent with our predictions. The Korean lax versus tense plosive distinction is absent from English (although phonetically it bears some resemblance to the initial aspiration contrast in English), and consequently bilinguals (heritage Korean speakers in the United States, who tend to be dominant in English) would have difficulty perceiving this contrast reliably, a difficulty that would become more profound with earlier attenuation of contact with Korean.

Accuracy on the /t/–/t*/ contrast is plotted by participant as a function of age of reduced contact in Figure 2. The horizontal reference line indicating the minimum score of Korean controls (excluding one outlier) is at 36% for

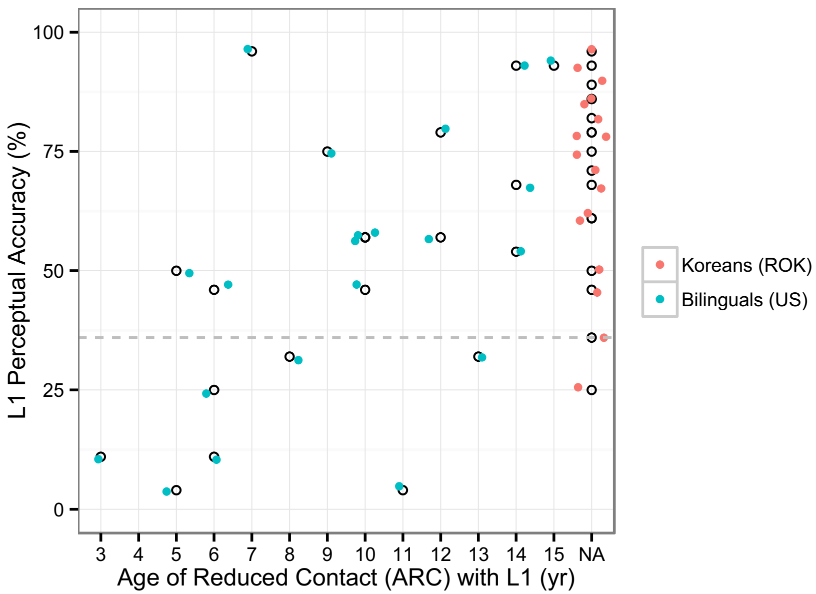

Figure 2 Accuracy for the /t/–/t*/ contrast, by age of reduced contact and group. Jittered points (in filled circles) are plotted over each combination of age of reduced contact and accuracy level contained in the dataset (in hollow circles) to show the number of data points represented by each hollow circle. The dotted line marks the bottom of the accuracy range for Korean controls (excluding outliers). [Color figure can be viewed at wileyonlinelibrary.com]

this contrast.[8] The relative difficulty of distinguishing /t/–/t*/ in comparison to /n/–/l/ is reflected in the fact that several bilinguals (7/21) are below the reference line. Consistent with a critical age boundary for L1 attrition of 12 (e.g., Yeni-Komshian et al., 2000), most (6/7) of these bilinguals had an age of reduced contact before 12 years. By contrast, among the bilinguals with an age of reduced contact later than 12 years, all but one fell into the Korean control range. Even the exception, with an age of reduced contact of 13 years, was close (at 32%) to the reference line. Further, this bilingual's low accuracy (relative to her age of reduced contact) may be attributable to the background variables examined. In particular, her L1 listening proficiency was lower than average (75/100, cf. group mean of 86.2), as was her lifetime relative L1 use (0.82, cf. group mean of 2.1), suggesting that she was using the L1 much less than the L2 at the time of study. As for the background predictors related to the bilinguals as a group, the results of Model 2B showed no effect of relative L1 use, relative L1 exposure, or L1 listening proficiency, $|\beta| < 0.092$, $|z| < 1.538$,

$p > .05$, but a significant effect of L1 education. The effect of L1 education was positive, $\beta = 0.020$, $z = 5.156$, $p < .001$, as was observed for the /n/–/l/ contrast.

Contrast 3 (Not Assimilable to a L2 Contrast): /s/–/s*/

As with the /t/–/t*/ contrast, the Korean control group showed a much higher level of accuracy for the /s/–/s*/ contrast than the bilingual group did (85% vs. 64%). In fact, the results of Model 1 (Table 4) indicated that Korean controls' likelihood of accuracy was significantly higher for /s/–/s*/ compared to /n/–/l/, $\beta = 0.806$, $z = 3.903$, $p < .001$. However, the bilinguals' likelihood of accuracy did not show this same increment for /s/–/s*/. On the contrary, the results of Model 2A (Table 5) showed that the bilinguals' likelihood of accuracy was significantly lower for /s/–/s*/ compared to /n/–/l/, $\beta = –3.818$, $z = –8.843$, $p < .001$. In other words, the bilinguals, but not the Korean controls, were less likely to be accurate on /s/–/s*/ compared to /n/–/l/ (just as they were for the /t/–/t*/ contrast).

Similar to the case of /t/–/t*/, the /s/–/s*/ contrast also showed (in Model 2A) a significant effect of age of reduced contact on the bilinguals' likelihood of accuracy. Summing together the simple coefficient for the effect of age of reduced contact at contrast /n/–/l/ and the interaction coefficient for the effect of age of reduced contact at contrast /s/–/s*/, $\beta = 0.320$, $z = 7.300$, $p < .001$, the same general relationship between age of reduced contact and accuracy held for /s/–/s*/ as for /t/–/t*/. The later a bilingual's age of reduced contact, the more likely s/he was to be accurate on a L1-specific contrast.

Crucially, however, the relationship between age of reduced contact and accuracy, while going in the same direction for the two tenseness contrasts, was stronger for /s/–/s*/ than for /t/–/t*/. This difference was apparent upon inspection of Model 2B (Table 6), which directly compared /s/–/s*/ to /t/–/t*/. There was a significant interaction coefficient for the effect of age of reduced contact at contrast /s/–/s*/, $\beta = 0.133$, $z = 3.186$, $p = .001$, which, in conjunction with the positive coefficient for the effect of age of reduced contact at the reference level of contrast (i.e., /t/–/t*/), meant that the positive relationship between age of reduced contact and accuracy observed for /t/–/t*/ was even more positive for /s/–/s*/.

These results are again consistent with our predictions. The Korean lax versus tense consonant distinction is absent in English. In the case of the fricatives /s/ and /s*/, the distinction does not bear a close phonetic resemblance to any contrast of English. Instead, the two members of the contrast are likely to

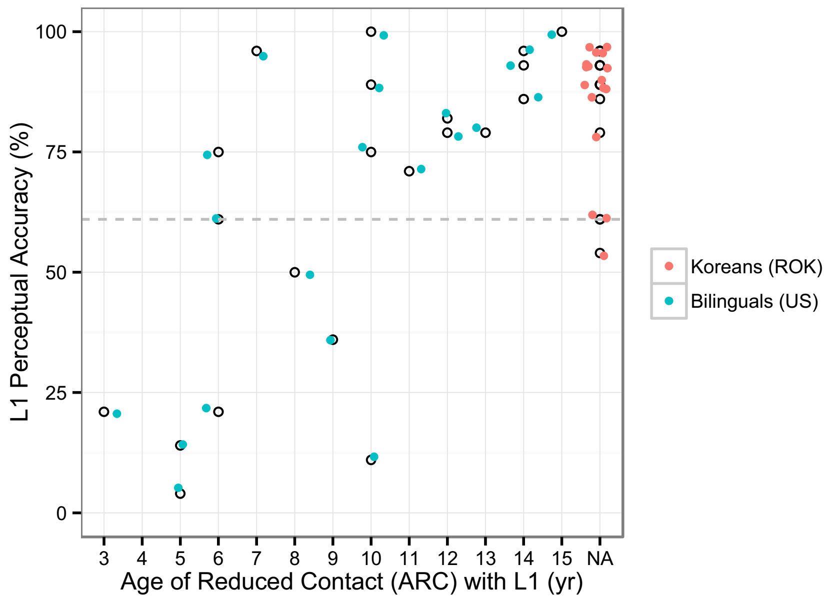

Figure 3 Accuracy for the /s/–/s*/ contrast, by age of reduced contact and group. Jittered points (in filled circles) are plotted over each combination of age of reduced contact and accuracy level contained in the dataset (in hollow circles) to show the number of data points represented by each hollow circle. The dotted line marks the bottom of the accuracy range for Korean controls (excluding outliers). [Color figure can be viewed at wileyonlinelibrary.com]

be assimilated to the same English category. The bilinguals thus had difficulty perceiving this contrast reliably; with even less of a possibility of phonological support from the L2, the effect of age of reduced contact here was even stronger than it was with /t/–/t*/.

Accuracy on the /s/–/s*/ contrast is plotted by participant as a function of age of reduced contact in Figure 3. The reference line indicating the minimum score of Korean controls (excluding one outlier) is at 61%. The difficulty of distinguishing /s/–/s*/ is reflected in the fact that several (7/21) bilinguals appear below the reference line. However, if the same age of reduced contact boundary for L1 attrition is applied here as in /t/–/t*/ (age 12), it can be seen that all of the bilinguals below the reference line fall to the left of this boundary. In other words, all bilinguals with an age of reduced contact after 12 years are above the reference line, without exception. In fact, the same can be said for all bilinguals with an age of reduced contact after 11 years. However, with only one data point for an age of reduced contact of 11, it is difficult to suggest this lower age of reduced contact as the critical turning point for L1 attrition. Thus, together with the results for the /t/–/t*/ contrast, the current data provided support for the age of 12 as a critical age for L1 attrition.

Finally, examination of the bilinguals' background variables in Model 2C (Table 7) revealed a similar pattern as found for /t/–/t*/. Whereas there was no effect of relative L1 use, relative L1 exposure, or L1 listening proficiency, $|\beta| < 0.242$, $|z| < 1.719$, $p > .05$, there was a significant effect of L1 education, which was again positive, $\beta = 0.017$, $z = 2.891$, $p = .004$.

Discussion

Summary of Findings

The goal of this study was to examine whether age of reduced contact with the L1 is a significant predictor of L1 attrition in speech perception. To this end, we conducted a perception experiment with L1 Korean–L2 English bilinguals in the United States and L1 Korean control speakers in Korea, which produced results supporting our three predictions.

Regarding our first prediction, bilinguals' perception of certain (namely, L1-specific) phonemic contrasts did indeed vary as a function of age of reduced contact. In addition, there was an effect of L1 education that was observed across contrasts. However, with the exception of relative L1 exposure in the case of /n/–/l/, the other factors included in modeling (e.g., L1 use, L1 listening proficiency) did not predict L1 perceptual ability. Thus, overall the findings provided partial support for the hypothesis that the earlier bilinguals are extensively exposed to a L2, the less likely they are to perceive L1 speech sounds accurately (Bylund, 2009; Montrul, 2008).

Regarding our second prediction, the effect of age of reduced contact on L1 perception varied in strength according to the assimilability of the L1 contrast to distinct L2 sounds. The less phonological support available from a L2 contrast, the stronger the effect of age of reduced contact. To summarize the effects of age of reduced contact for the three L1 contrasts examined, Figure 4 shows the bilinguals' accuracies for all three contrasts according to age of reduced contact, with best-fit regression lines. In Figure 4, the flat slope of the best-fit line reflects the null effect of age of reduced contact on accuracy for /n/–/l/ (a contrast clearly paralleled by a L2 contrast), whereas the positive slope of the best-fit line in Figure 4 reflects the significant effect of age of reduced contact on accuracy for /t/–/t*/ (a contrast less clearly paralleled by a L2 contrast). The stronger effect of age of reduced contact on accuracy for /s/–/s*/ (a contrast not paralleled by a L2 contrast) can be seen in the steeper positive slope of the best-fit line in Figure 4c.

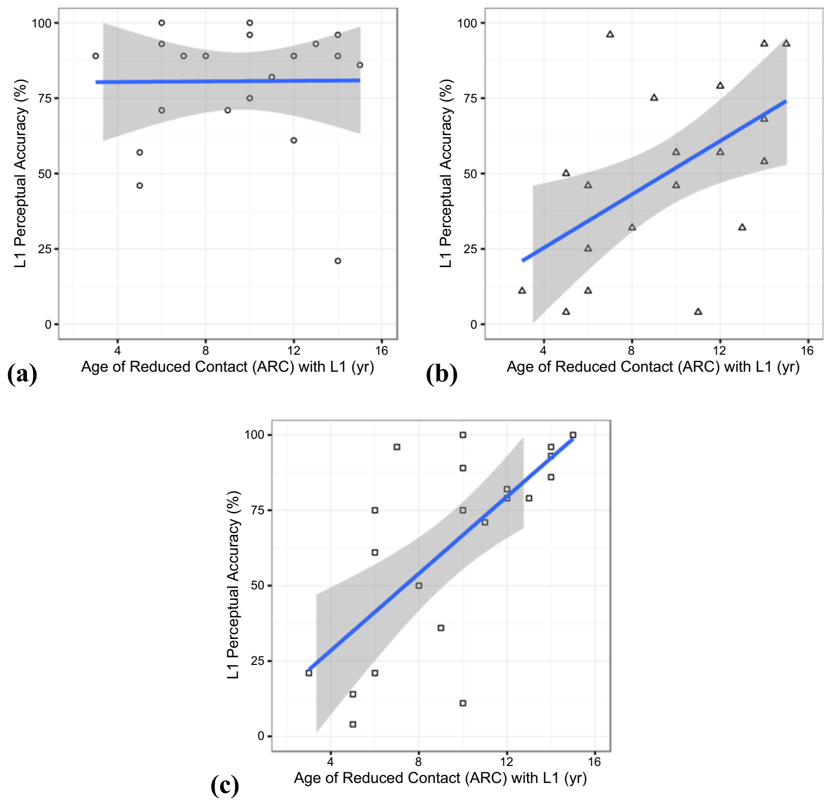

Figure 4 Bilinguals' accuracy by age of reduced contact for the three contrasts: (a) /n/–/l/, (b) /t/–/t*/, and (c) /s/–/s*/. The shaded area in each plot represents the 95% confidence interval around the regression line. [Color figure can be viewed at wileyonlinelibrary.com]

Finally, regarding our third prediction, we observed a pattern across the three L1 contrasts examined that was broadly consistent with 12 years of age as a turning point for L1 perceptual attrition. For both L1-specific contrasts (/t/–/t*/, /s/–/s*/), the bilinguals with an age of reduced contact after 12 years (with one exception, who was nevertheless close to the low end of the Korean control range) fell into the Korean control range, while only half of the bilinguals with an age of reduced contact before 12 years did. These results converge with previous findings that have addressed domains other than speech perception. To be specific, in Yeni-Komshian et al. (2000), bilinguals with an AOA for the L2 before age 5 showed nativelike pronunciation in the L2 but not the L1. On the other hand, bilinguals with

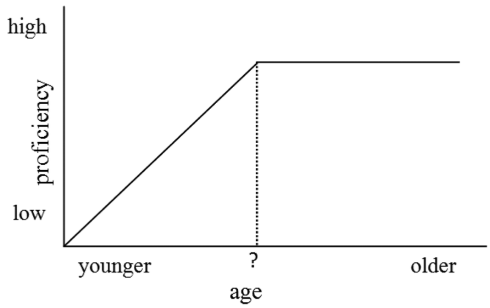

Figure 5 Schematization of age effects in L1 attrition (adapted from Montrul, 2008, p. 267). The vertical axis shows L1 proficiency; the horizontal axis shows age of reduced contact with the L1. The dotted line marks the end of a critical period for L1 attrition.

an AOA after age 12 showed nativelike pronunciation of the L1 but not the L2.

Although Yeni-Komshian et al. (2000) explained such different turning points for L1 and L2 attainment in terms of nativelike proficiency in one language occurring at the expense of the other language, our results suggested that bilinguals' nativeness in one language does not necessarily result from sacrificing the other language. In our regression analyses, although we observed a clear effect of age of reduced contact, we observed no effect of self-identified language dominance, relative L1 use, or L1 listening proficiency on the likelihood of L1 perceptual accuracy. That is, dominance in the L2 (i.e., nondominance in the L1), low L1 use, and low L1 listening comprehension did not necessarily doom a bilingual to L1 perceptual attrition. To take one example, one bilingual, who identified as dominant in the L2 and showed below-average levels of both relative L1 use and L1 listening proficiency, still showed nearly perfect accuracy (96%) in perceiving L1-specific contrasts. Thus, L1 attrition can be described as a function of age of reduced contact rather than as a function of language dominance, use, and/or proficiency, as shown in Figure 5. According to Yeni-Komshian et al., the turning point shown in Figure 5 (beyond which L1 attrition is unlikely to occur) corresponds to age 12, at least for production (overall accent). Before this critical age, the adaptability that facilitates L2 acquisition might also allow a speaker to forget the L1 more easily than after this age. The contribution of the current study is in providing evidence for this critical age in the domain of perception as well.

However, our claim regarding a developmental turning point for L1 attrition applies to L1-specific (i.e., difficult) phonemic contrasts that do not receive support from the L2 phonology. We have argued that the magnitude of age effects in L1 perception will actually differ according to the tested features of the L1—in particular, their level of difficulty vis-à-vis the L2 phonological system—because bilinguals' perception of L1 speech sounds is expected to be influenced by their L2 system, as suggested in prior work. In Ventureyra et al. (2004), for example, Korean adoptees to France failed to accurately perceive L1 Korean phonemes that are difficult for native French speakers to distinguish but succeeded with ones that are easy for native French speakers. On the one hand, the failure to perceive L1 phonemes is consistent with the view that "one's native language is not a fixed and stable system but rather a fluid and changeable one that is highly subject to the influence of a well-developed second system" (Major, 1992, p. 204), a view that may need to be extended to earlier stages of L2 development as well (e.g., see Tice & Woodley, 2012). On the other hand, the success on easy L1 contrasts provides evidence for a facilitative effect of close correspondence with L2 contrasts. Therefore, to test for L1 attrition, we specifically examined two L1 contrasts predicted to be difficult for native speakers of the L2 so that L1 attrition in early bilinguals could be clearly observed.

Performance of Korean Control Participants

In addition to the bilingual participants with early ages of reduced contact, some Korean control participants also performed relatively poorly in the speeded sequence recall task. A total of five, seven, and three Korean controls showed less than 70% accuracy for the /n/–/l/, /t/–/t*/, and /s/–/s*/ contrasts, respectively, which merits an explanation. Because the control participants were native Korean speakers who had never lived in an English-speaking country for more than 6 months before age 19 and had been educated in Korean continuously from kindergarten through college, their relatively poor performance on this task was unlikely to be due to a lack of perceptual ability in the L1. Rather, their low accuracy levels can be attributed to two factors: task demands and specific linguistic aspects of their variety of Korean.

The speeded sequence recall task that we used required not only perceptual ability but also high auditory working memory capacity because participants had to remember four auditory items in a sequence in order to enter a correct response. In postexperiment debriefings, Korean control participants reported that it was far more demanding to remember sounds in a four-item sequence than to distinguish each sound. Thus, variation in the accuracy of Korean controls may reflect, to some degree, individual differences in working memory. However, because we did not collect measures of working memory directly, we can only speculate about this point. It is also worth pointing out that if participants had not paid attention to stimulus order, their accuracy would have suffered just as much as if they were unable to distinguish the contrasts to begin with. In light of the fact that no Korean control participants obtained perfect scores on any contrasts in this task while four bilinguals did (two each on /n/–/l/ and /s/–/s*/), it is therefore possible that at least some Korean controls had not concentrated during the experiment as much as the high-performing bilinguals had.

Apart from variation in working memory and levels of concentration during the task, the Korean controls' performance could also have been affected by a specific aspect of the phonology of Korean as spoken in the Republic of Korea. In particular, the difficulty of the /n/–/l/ contrast could be increased for the Korean control group by the fact that, in their variety of Korean, /l/ is often altered to /n/ in word-initial position (Choo & O'Grady, 2003).[9] Thus, in the case of /lak^{h}a/, although visual and auditory inspection of the stimuli confirmed that the speakers who recorded the stimuli produced this item as acoustically distinct from /nak^{h}a/, the relative rarity of /l/-initial items in the Korean lexicon (compared to the abundance of /n/-initial items) could lead to the /l/ sounding similar to /n/ for native Korean speakers, which would have made the /n/–/l/ contrast difficult to discriminate for the Korean control group. In contrast, English freely allows contrasts between /n/ and /l/ in word-initial position, and accordingly, regardless of position, native English speakers are not expected to have difficulty distinguishing the /n/–/l/ contrast.[10]

Incomplete L1 Acquisition or L1 Attrition

Returning to the bilingual group, given that L1 attrition is often confounded with incomplete L1 acquisition, the lower observed accuracy levels of the bilinguals (in particular, those who had experienced a reduction in L1 contact from an early age) may reflect either incomplete L1 acquisition or L1 attrition. Although these two concepts are not mutually exclusive (i.e., they can occur simultaneously or sequentially in early bilingualism), they refer to different processes of linguistic development (Montrul, 2008, p. 21), and the question of which process is responsible for lower proficiency with a certain L1 feature can be addressed with either longitudinal or cross-sectional approaches. If the bilinguals are children, longitudinal research is preferred. For example, Anderson (1999) longitudinally examined two bilingual siblings' error rates in L1 (Spanish) gender agreement. At the first observation point, the older sibling (age 6 years) showed no errors while the younger one (age 4 years) showed an error rate of 8%. Almost 2 years later, their error rates were both higher (5.8% and 18.2%, respectively). Thus, although both siblings showed a decline in L1 accuracy over time, this decline has a different explanation for each sibling. Under the assumption that ceiling accuracy in production of a L1 feature or pattern reflects full acquisition of the L1 target, the older sibling's case can be considered L1 attrition because she reached full acquisition of gender agreement (reflected in error-free production) before beginning to show errors. In contrast, the younger sibling's case can be considered incomplete L1 acquisition followed by attrition because she did not show evidence of having fully acquired the target patterns before making more errors.

On the other hand, when data are obtained from older bilinguals as in the present study, cross-sectional research is possible. In the present study, for instance, adult bilinguals representing a wide range of ages of reduced contact were examined simultaneously, leading to the observation that an age of reduced contact before 12 years was correlated with a failure to perceive L1-specific phonemes as accurately as native controls. This result, however, does not allow us to draw firm conclusions about whether the lower accuracies of the bilinguals with ages of reduced contact before 12 years followed from attrition specifically (as opposed to incomplete acquisition). There is evidence that contrasts of the type tested in this study (namely, laryngeal contrasts) are perceptually acquired in other languages before 1 year of age (e.g., Burns, Yoshida, Hill, & Werker, 2007), which suggests that the target Korean laryngeal contrasts (/t/–/t*/, /s/–/s*/) are likely to have been perceptually acquired by age 3 (i.e., the low end of the age of reduced contact range represented by our participants). In this case, our findings would reflect attrition only. The fact remains, however, that to our knowledge there are no empirical results that have demonstrated perceptual acquisition of these Korean contrasts by age 3 directly.

Thus, whether our findings reflect attrition and/or incomplete acquisition remains an open question for further study, and it would be useful to conduct a follow-up study examining L1 Korean children in Korea who are younger than age 12, in order to determine what typical developmental levels of speech perception look like in children at these younger ages. If, for example, L1 Korean children slightly younger than age 12 (e.g., age 10) were to show accuracy levels above the adult reference lines in Figures 1–3, this would provide evidence that the lower accuracies of adult bilinguals with an age of reduced contact of 10 years reflect L1 attrition. On the other hand, if L1 children's accuracies are also lower than the reference line, then the lower accuracies of adult bilinguals with ages of reduced contact matching the L1 children's ages can be attributed, at least in part, to incomplete L1 acquisition.

Limitations and Future Study

Although L1 education, L1 use, and L1 proficiency levels have previously been observed to play a role in bilinguals' L1 attrition (Hakuta & D'Andrea, 1992), only L1 education was found to be a significant predictor in this study. For the L1 experience variables, the present study employed a specially designed language history questionnaire to obtain a detailed description of participants' education in, and use of, the L1, expressed in hours and months according to major educational milestones. The fact remains, however, that this questionnaire measured prior L1 experience through retrospective self-reporting, which might not be stable or objective (Bylund, Abrahamsson, & Hyltenstam, 2010). It is possible, therefore, that the nonsignificance of the L1 use variable in this study was related to a less reliable measurement of L1 use. Furthermore, L1 education, which may be more reliably measured via retrospective self-reporting than L1 use, could serve as a better proxy for amount of L1 use compared to the actual L1 use variable. In this case, the observed significance of the L1 education variable may indeed reflect an effect of L1 use and/or exposure. Thus, we are careful to point out that the nonsignificance of the L1 use variable in this study does not mean that L1 use plays no role in L1 attrition.

The limitation associated with the L1 use variable reflects a general problem in L1 attrition research, that is, the difficulty of obtaining an exact lifetime measure of a speaker's use of (or, at least, exposure to) the L1 prior to the time of study. This problem is compounded by the fact that, in spite of a participant's concrete reporting of the amount of prior L1 contact and use, it cannot be guaranteed that the type or quality of contact with the L1 remained consistent before and after immigration. Thus, future research on L1 perceptual attrition should consider not only data about the quantity of L1 contact but also data about its quality (see de Leeuw et al., 2010, for an example of this type of approach with respect to L1 attrition of pronunciation).

An additional limitation of the present study is in the nature of the participant sample. Although the sample included a total of 21 bilinguals with ages of reduced contact ranging from 3 to 15 years, such that each age of reduced contact was represented by up to four data points, there were also, by luck of the draw (i.e., life histories of those who happened to participate in the study), some ages of reduced contact within the observed range that were represented by no data points. Therefore, on the basis of this study alone, it is not possible to make a definitive claim about a critical age for L1 attrition. Nevertheless, the current results contribute to the attrition literature in two ways: (a) by providing evidence of selective age effects in L1 perceptual attrition (i.e., only with L1 phonemic contrasts that are not closely paralleled by L2 contrasts) and (b) by suggesting that a turning point previously found in the domain of L1 pronunciation (namely, age 12) may also apply to the perception of L1-specific contrasts. It will be crucial to replicate this type of study with larger samples—in particular, with different L1–L2 pairs and different kinds of L1-specific features—to understand the extent of these age effects in L1 attrition as well as the generality of age 12 as a critical age in this regard.

Besides extending the domain of inquiry to different features in other bilingual populations, an additional avenue for future research on L1 attrition is in the role of L1 education, the only background variable besides L1 exposure that was observed to have an effect on attrition in the present study. This effect of L1 education (wherein more education was associated with a lower likelihood of perceptual attrition) converges with other research that had investigated domains other than speech perception (Bylund & Díaz, 2012; Hakuta & D'Andrea, 1992). However, whereas Bylund and Díaz suggested that the effects of L1 education are short term (i.e., do not persist long after the end of L1 education), we found consistent effects of L1 education even with a participant sample that included several individuals who were not currently engaged in a L1 educational experience. Thus, insofar as L1 education may have an inhibitory effect on L1 attrition, the nature of this effect needs to be better understood, especially in light of the fact that L1 education is one of the few background variables linked to attrition that could be impacted significantly by governments and policy makers.

Finally, a challenge for future work on attrition will be to reconcile findings of bilinguals' divergence from nativelike perceptual patterns for the L1 (as documented in the current study) with findings of stability of nativelike perception. A recurring theme of research on international adoptees as well as typical immigrant bilinguals is the perseverance of traces of early acquired L1 knowledge in the face of reduced contact with the L1, which is reflected in a perceptual advantage over naïve listeners and late-onset L2 learners (Lee-Ellis, 2012; Oh, Au, & Jun, 2010; Tees & Werker, 1984) and/or unconscious processing differences (Pierce, Klein, Chen, Delcenserie, & Genesee, 2014). That is, contrary to the results of Ventureyra et al. (2004), it has often been observed that the L1 is not completely forgotten, even in conditions that favor total loss. Some studies, moreover, show early bilinguals, including bilinguals who have become dominant in the L2, patterning like native listeners in L1 perceptual tasks (Chang, 2016; Lee-Ellis, 2012; Lukyanchenko & Gor, 2011). In light of this body of work, the current findings invite the question of when a reduction in L1 contact (and/or switched dominance) leads to L1 perceptual attrition and when it does not. While the current study has emphasized the role played by phonological overlap with the L2, these previous studies have pointed to a number of other factors that might play a role in whether L1 attrition is observed, such as task demands and frequency of occurrence of the given feature in the L1.[11] It remains to be seen how these various factors will be teased apart in terms of their relative contributions to the likelihood of L1 maintenance versus L1 attrition.

Conclusion

In closing, the present study showed clear age effects in L1 attrition. Korean–English bilinguals' speech perception in L1 Korean was predicted by their age of reduced contact with the L1, after controlling for other relevant background variables, such as L1 proficiency and L1 use. To be specific, the earlier bilinguals were extensively exposed to L2 English, the less likely they were to perceive L1 speech sounds accurately (Bylund, 2009; Montrul, 2008). Crucially, however, this effect was limited to L1-specific contrasts. Our results were also consistent with the age of 12 as a turning point between the occurrence of L1 perceptual attrition and the maintenance of nativelike L1 perceptual abilities.

Despite the limitations of this study, our findings have significant implications for research as well as for practice. As emphasized in Bylund (2009), "research on maturational constraints in language attrition has barely taken its first steps and it seems clear that this is a promising topic for future inquiry regarding maturational constraints and language development in general" (p. 707). Additionally, research in this area can shed light on the reality that "most immigrant children [in predominantly monolingual environments such as the United States] tend to lose, or severely limit their use of, their heritage language" (Knightly et al., 2003, p. 473). Consequently, the findings of the present line of research are expected not only to refine our understanding of the nature of language memory over the lifespan but also to provide an empirical basis for immigrant families and early childhood educators to make more informed decisions regarding language education for bilinguals.

Final revised version accepted 10 May 2017

Notes

1 Maturation can be understood as "a process with a biologically anchored terminus at puberty, after which the process has come to an end and the individual is 'mature'" (Bylund, 2009, p. 708).
2 Attrition refers to the "loss of some L1 elements, seen in inability to produce, perceive, or recognize particular rules, lexical items, concepts, or categorical distinctions due to L2 influence" (Pavlenko, 2004, p. 47).
3 Unfortunately, the authors do not provide a specific definition of *minimal use*.
4 The first member of the fricative contrast (/s/) is also referred to in the literature as lax, lenis, or plain. However, because the phonological classification of /s/ as lax

(on par with the lax plosives) as opposed to aspirated (on par with the aspirated plosives) is controversial (e.g., see Chang, 2013a), here it is referred to in opposition to tense /s*/ as *nontense*.

5 As this study was about L1 attrition, we were interested in early (as opposed to late) bilinguals. Thus, individuals who were late bilinguals (age of L2 onset post-puberty into adulthood) according to Montrul's (2008) speaker classification were not included in the study. Moreover, given that Korean–English simultaneous bilinguals, who either were born in or moved to the L2-speaking country before age 2, have been shown to have difficulty perceiving the L1 Korean /s/–/s*/ contrast (Lee-Ellis et al., 2009), bilinguals with an age of reduced contact before age 2 were not included either.

6 Because it is not clear whether an hour of exposure during one age block should count as equivalent to an hour of exposure during another age block, this calculation was carried out assuming that the quality and quantity of language exposure were homogeneous within an age block but possibly heterogeneous between age blocks. This limitation is discussed in more detail below.

7 For example, whereas the correlation between age of reduced contact and absolute L1 use was .75, the correlation between age of reduced contact and relative L1 use was considerably lower at .56.

8 One may note that the Korean control group tended to show lower accuracy on the /t/–/t*/ contrast compared to the /n/–/l/ contrast. Although this disparity is not important for our purposes, we attribute it to the perceptual confusability of lax stops (which are phonetically aspirated in initial position) and tense stops (which are sometimes described as laryngealized) in the environment of a following aspirated stop (namely, /k^h/). In fact, the perceptual difficulty of these types of sequences is known to lead to phonotactic restrictions against consecutive laryngeals, as in Quechua (Gallagher, 2012) as well as the history of Indo-European (Grassmann's Law; e.g., see Collinge, 1985).

9 According to Choo and O'Grady (2003), the alternation between /l/ and /n/ "is found in Sino-Korean roots, depending on their position in a word" (p. 73, fn. 4). The example they point out is the root meaning *chaos*: /lan/ inside a word (e.g., /so+lan/ *commotion*), but /nan/ at the beginning of a word (e.g., /nan+li/ *uproar*).

10 This is consistent with a group disparity observed in postexperiment debriefings. The Korean controls typically commented that the /n/–/l/ contrast was the most difficult among the three, whereas the bilinguals (the majority of whom were dominant in English) said that the /n/–/l/ contrast was the easiest.

11 An anonymous reviewer pointed out that markedness relations could be another factor influencing the relative susceptibility of various L1 contrasts to perceptual attrition. We agree that markedness may be another relevant factor, while noting the practical difficulty of teasing apart the effect of markedness from the effect of L1–L2 similarity (i.e., assimilability to L2 contrasts). Because languages are, overall, more likely to contain unmarked than marked structures, the locus of any

phonological overlap between them is much more likely to occur in relatively unmarked structures. Consequently, to identify an effect of markedness distinct from L1–L2 similarity, it would be necessary to examine L1 attriters who exemplify an unusual L1–L2 pairing: (a) a L1 containing highly marked contrasts that closely resemble similar, highly marked contrasts that happen to occur in the L2 as well or (b) a L1 containing unmarked contrasts that are, extraordinarily, absent from the L2.

References

Ammerlaan, T. (1996). *"You get a bit wobbly . . . ": Exploring bilingual lexical retrieval processes in the context of first language attrition*. Unpublished doctoral dissertation, Katholieke Universiteit Nijmegen, The Netherlands.

Anderson, R. T. (1999). Loss of gender agreement in L1 attrition: Preliminary results. *Bilingual Research Journal*, *23*, 389–408. https://doi.org/10.1080/15235882.1999.10162742

Au, T. K.-f., Oh, J. S., Knightly, L. M., Jun, S.-A., & Romo, L. (2008). Salvaging a childhood language. *Journal of Memory and Language*, *58*, 998–1011. https://doi.org/10.1016/j.jml.2007.11.001

Best, C. T., & Tyler, M. D. (2007). Nonnative and second-language speech perception: Commonalities and complementarities. In O.-S. Bohn & M. J. Munro (Eds.), *Language experience in second language speech learning: In honor of James Emil Flege* (pp. 13–34). Amsterdam: John Benjamins. https://doi.org/10.1075/lllt.17.07bes

Bowers, J. S., Mattys, S. L., & Gage, S. H. (2009). Preserved implicit knowledge of a forgotten childhood language. *Psychological Science*, *20*, 1064–1069. https://doi.org/10.1111/j.1467-9280.2009.02407.x

Burns, T. C., Yoshida, K. A., Hill, K., & Werker, J. F. (2007). The development of phonetic representation in bilingual and monolingual infants. *Applied Psycholinguistics*, *28*, 455–474. https://doi.org/10.1017/S0142716407070257

Bylund, E. (2009). Maturational constraints and first language attrition. *Language Learning*, *59*, 687–715. https://doi.org/10.1111/j.1467-9922.2009.00521.x

Bylund, E., Abrahamsson, N., & Hyltenstam, K. (2010). The role of language attitude in first language attrition: The case of pre-pubescent attriters. *Applied Linguistics*, *31*, 443–464. https://doi.org/10.1093/applin/amp059

Bylund, E., & Díaz, M. (2012). The effects of heritage language instruction on first language proficiency: A psycholinguistic perspective. *International Journal of Bilingual Education and Bilingualism*, *15*, 593–609. https://doi.org/10.1080/13670050.2012.676620

Chang, C. B. (2012). Rapid and multifaceted effects of second-language learning on first-language speech production. *Journal of Phonetics*, *40*, 249–268. https://doi.org/10.1016/j.wocn.2011.10.007

Chang, C. B. (2013a). The production and perception of coronal fricatives in Seoul Korean: The case for a fourth laryngeal category. *Korean Linguistics*, *15*, 7–49. https://doi.org/10.1075/kl.15.1.02cha

Chang, C. B. (2013b). A novelty effect in phonetic drift of the native language. *Journal of Phonetics*, *41*, 520–533. https://doi.org/10.1016/j.wocn.2013.09.006

Chang, C. B. (2016). Bilingual perceptual benefits of experience with a heritage language. *Bilingualism: Language and Cognition*, *19*, 791–809. https://doi.org/10.1017/S1366728914000261

Choo, M., & O'Grady, W. (2003). *The sounds of Korean: A pronunciation guide*. Honolulu: University of Hawaii Press.

Collinge, N. E. (1985). *The laws of Indo-European*. Amsterdam: John Benjamins. https://doi.org/10.1075/cilt.35

de Leeuw, E. (2014). Maturational constraints in bilingual speech. In E. M. Thomas & I. Mennen (Eds.), *Advances in the study of bilingualism* (pp. 25–37). Clevedon, UK: Multilingual Matters.

de Leeuw, E., Mennen, I., & Scobbie, J. M. (2012). Singing a different tune in your native language: L1 attrition of prosody. *International Journal of Bilingualism*, *16*, 101–116. https://doi.org/10.1177/1367006911405576

de Leeuw, E., Mennen, I., & Scobbie, J. M. (2013). Dynamic systems, maturational constraints, and phonetic attrition. *International Journal of Bilingualism*, *17*, 683–700. https://doi.org/10.1177/1367006912454620

de Leeuw, E., Opitz, C., & Lubińska, D. (2013). Dynamics of first language attrition across the lifespan. *International Journal of Bilingualism*, *17*, 667–674. https://doi.org/10.1177/1367006912454618

de Leeuw, E., Schmid, M. S., & Mennen, I. (2010). The effects of contact on native language pronunciation in an L2 migrant setting. *Bilingualism: Language and Cognition*, *13*, 33–40. https://doi.org/10.1017/S1366728909990289

DeKeyser, R. M. (2012). Age effects in second language learning. In S. M. Gass & A. Mackey (Eds.), *The Routledge handbook of second language acquisition* (pp. 442–460). London: Routledge.

DeKeyser, R. M., & Larson-Hall, J. (2005). What does the critical period really mean? In J. F. Kroll & A. M. B. de Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. 88–108). New York: Oxford University Press.

Dmitrieva, O., Jongman, A., & Sereno, J. (2010). Phonological neutralization by native and non-native speakers: The case of Russian final devoicing. *Journal of Phonetics*, *38*, 483–492. https://doi.org/10.1016/j.wocn.2010.06.001

Dupoux, E., Sebastián-Gallés, N., Navarrete, E., & Peperkamp, S. (2008). Persistent stress "deafness": The case of French learners of Spanish. *Cognition*, *106*, 682–706. https://doi.org/10.1016/j.cognition.2007.04.001

Flege, J. E., Yeni-Komshian, G. H., & Liu, S. (1999). Age constraints on second-language acquisition. *Journal of Memory and Language*, *41*, 78–104. https://doi.org/10.1006/jmla.1999.2638

Gallagher, G. (2012). Perceptual similarity in non-local laryngeal restrictions. *Lingua*, *122*, 112–124. https://doi.org/10.1016/j.lingua.2011.11.012

Granena, G., & Long, M. H. (2013). Age of onset, length of residence, language aptitude, and ultimate L2 attainment in three linguistic domains. *Second Language Research*, *29*, 311–343. https://doi.org/10.1177/0267658312461497

Guion, S. G. (2005). Knowledge of English word stress patterns in early and late Korean-English bilinguals. *Studies in Second Language Acquisition*, *27*, 503–533. https://doi.org/10.1017/S0272263105050230

Hakuta, K., & D'Andrea, D. (1992). Some properties of bilingual maintenance and loss in Mexican background high-school students. *Applied Linguistics*, *13*, 72–99. https://doi.org/10.1093/applin/13.1.72

Hopp, H., & Schmid, M. S. (2013). Perceived foreign accent in first language attrition and second language acquisition: The impact of age of acquisition and bilingualism. *Applied Psycholinguistics*, *34*, 361–394. https://doi.org/10.1017/S0142716411000737

Hyltenstam, K., & Abrahamsson, N. (2003). Maturational constraints in SLA. In C. J. Doughty & M. H. Long (Eds.), *The handbook of second language acquisition* (pp. 539–588). Oxford, UK: Blackwell. https://doi.org/10.1002/9780470756492.ch17

Hyltenstam, K., Bylund, E., Abrahamsson, N., & Park, H.-S. (2009). Dominant-language replacement: The case of international adoptees. *Bilingualism: Language and Cognition*, *12*, 121–140. https://doi.org/10.1017/S1366728908004008

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language*, *59*, 434–446. https://doi.org/10.1016/j.jml.2007.11.007

Johnson, J. S., & Newport, E. L. (1989). Critical period effects in second language learning: The influence of maturational state on the acquisition of English as a second language. *Cognitive Psychology*, *21*, 60–99. https://doi.org/10.1016/0010-0285(89)90003-0

Knightly, L. M., Jun, S.-A., Oh, J. S., & Au, T. K.-f. (2003). Production benefits of childhood overhearing. *Journal of the Acoustical Society of America*, *114*, 465–474. https://doi.org/10.1121/1.1577560

Korea Institute for Curriculum and Evaluation. (2010). The 18th test of proficiency in Korean. Retrieved May 8, 2017, from https://www.topikguide.com/download-18th-topik-papers-with-answers/

Kroll, J. F., & de Groot, A. M. B. (2005). Preface and acknowledgements. In J. F. Kroll & A. M. B. de Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. v–vi). New York: Oxford University Press.

Lee-Ellis, S. (2012). *Looking into bilingualism through the heritage speaker's mind*. Unpublished doctoral dissertation, University of Maryland, College Park, MD.

Lee-Ellis, S., Idsardi, W., & Phillips, C. (2009). *Distinguishing effects of early exposure and language dominance: Speech perception by Korean heritage speakers*. Poster presented at the 34th Boston University Conference on Language Development, Boston.

Lukyanchenko, A., & Gor, K. (2011). Perceptual correlates of phonological representations in heritage speakers and L2 learners. In N. Danis, K. Mesh, & H. Sung (Eds.), *Proceedings of the 35th Annual Boston University Conference on Language Development* (pp. 414–426). Somerville, MA: Cascadilla Press.

MacKay, I. R. A., Flege, J. E., & Imai, S. (2006). Evaluating the effects of chronological age and sentence duration on degree of perceived foreign accent. *Applied Psycholinguistics*, *27*, 157–183. https://doi.org/10.1017/S0142716406060231

Major, R. C. (1992). Losing English as a first language. *The Modern Language Journal*, *76*, 190–208. https://doi.org/10.2307/329772

Mayr, R., Price, S., & Mennen, I. (2012). First language attrition in the speech of Dutch-English bilinguals: The case of monozygotic twin sisters. *Bilingualism: Language and Cognition*, *15*, 687–700. https://doi.org/10.1017/S136672891100071X

Mazzaro, N., Cuza A., & Colantoni, L. (2016). Age effects and the discrimination of consonantal and vocalic contrasts in heritage and native Spanish. In C. Tortora, M. den Dikken, I. L. Montoya, & T. O'Neill (Eds.), *Romance linguistics 2013: Selected papers from the 43rd Linguistic Symposium on Romance Languages (LSRL)* (pp. 277–299). Amsterdam: John Benjamins. https://doi.org/10.1075/rllt.9.15maz

Montrul, S. A. (2008). *Incomplete acquisition in bilingualism: Re-examining the age factor*. Amsterdam: John Benjamins. https://doi.org/10.1075/sibil.39

Oh, J. S., Au, T. K.-f., & Jun, S.-A. (2010). Early childhood language memory in the speech perception of international adoptees. *Journal of Child Language*, *37*, 1123–1132. https://doi.org/10.1017/S0305000909990286

Oh, J. S., Jun, S.-A., Knightly, L. M., & Au, T. K.-f. (2003). Holding on to childhood language memory. *Cognition*, *86*, 53–64. https://doi.org/10.1016/S0010-0277(02)00175-0

Pallier, C., Bosch, L., & Sebastián-Gallés, N. (1997). A limit on behavioral plasticity in speech perception. *Cognition*, *64*, B9–B17. https://doi.org/10.1016/S0010-0277(97)00030-9

Pavlenko, A. (2004). L2 influence and L1 attrition in adult bilingualism. In M. S. Schmid, B. Köpke, M. Keijzer, & L. Weilemar (Eds.), *First language attrition: Interdisciplinary perspectives on methodological issues* (pp. 47–60). Amsterdam: John Benjamins. https://doi.org/10.1075/sibil.28.04pav

Pelc, L. A. (2001). *L1 lexical, morphological and morphosyntactic attrition in Greek-English bilinguals*. Unpublished doctoral dissertation, City University of New York, New York.

Pierce, L. J., Klein, D., Chen, J.-K., Delcenserie, A., & Genesee, F. (2014). Mapping the unconscious maintenance of a lost first language. *Proceedings of the National Academy of Sciences of the United States of America*, *111*, 17314–17319. https://doi.org/10.1073/pnas.1409411111

Schmid, M. S., & Hopp, H. (2014). Comparing foreign accent in L1 attrition and L2 acquisition: Range and rater effects. *Language Testing*, *31*, 367–388. https://doi.org/10.1177/0265532214526175

Schmidt, A. M. (2007). Cross-language consonant identification: English and Korean. In O.-S. Bohn & M. J. Munro (Eds.), *Language experience in second language speech learning: In honor of James Emil Flege* (pp. 185–200). Amsterdam: John Benjamins. https://doi.org/10.1075/lllt.17.18sch

Sebastián-Gallés, N., & Soto-Faraco, S. (1999). Online processing of native and non-native phonemic contrasts in early bilinguals. *Cognition*, *72*, 111–123. https://doi.org/10.1016/S0010-0277(99)00024-4

Tees, R. C., & Werker, J. F. (1984). Perceptual flexibility: Maintenance or recovery of the ability to discriminate non-native speech sounds. *Canadian Journal of Psychology*, *38*, 579–590. https://doi.org/10.1037/h0080868

Tice, M., & Woodley, M. (2012). Paguettes and bastries: Novice French learners show shifts in native phoneme boundaries. *UC Berkeley Phonology Lab Annual Report*, *2012*, 72–75.

Tsukada, K., Birdsong, D., Bialystok, E., Mack, M., Sung, H., & Flege, J. (2005). A developmental study of English vowel production and perception by native Korean adults and children. *Journal of Phonetics*, *33*, 263–290. https://doi.org/10.1016/j.wocn.2004.10.002

Ventureyra, V. A. G., Pallier, C., & Yoo, H. (2004). The loss of first language phonetic perception in adopted Koreans. *Journal of Neurolinguistics*, *17*, 79–91. https://doi.org/10.1016/S0911-6044(03)00053-8

Yeni-Komshian, G. H., Flege, J., & Liu, S. (2000). Pronunciation proficiency in the first and second languages of Korean-English bilinguals. *Bilingualism: Language and Cognition*, *3*, 131–149.