

Language contact in bilingualism: Phonetic system interactions

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1. Introduction

Many studies in the past decade have shown that "earlier is better" as far as learning a second language (L2) is concerned. That is, individuals who began learning their L2 in late adolescence or early adulthood ("late bilinguals") usually resemble native speakers of the L2 less than individuals who began learning their L2 in childhood ("early bilinguals") do. Early bilinguals have been shown to resemble L2 native speakers to a greater extent than late bilinguals in terms of sensitivity to the grammatical properties of the L2 (Flege, Yeni-Komshian & Liu 1999; DeKeyser 2000) as well as in terms of the online processing of L2 sentences (Liu et al. 1992; McDonald 2000; Guillelmon & Grosjean 2001). Other studies have shown similar differences in the production and perception of L2 speech. For example, early bilinguals generally have milder foreign accents in the L2 than late bilinguals do (Flege et al. 1995a; Flege, Yeni-Komshian & Liu 1999). Also, early bilinguals have been found to produce and perceive L2 vowels more like L2 native speakers than late bilinguals do (Munro et al. 1996; Flege 1992; Flege, MacKay & Meador 1999; Piske et al. in press; Flege et al. submitted), to produce and perceive L2 consonants more accurately than late bilinguals do (Flege 1991; Flege et al. 1995b; MacKay, Meador & Flege 2001; MacKay, Flege, Piske & Schirru 2001), and to recognize L2 words presented in noise more effectively (Meador et al. 2000).

There is controversy as to the basis for the age effects just reported. The most common explanation for such effects is that L2 learning is limited by maturational constraints (Johnson & Newport 1989). On this view, some mechanism(s) that is(are) needed for successful L1 acquisition work(s) less effectively, or become(s) inaccessible for use in L2 acquisition as humans mature. Scovel (1988) hypothesized that a critical period for L2 speech learning ends at around the age of 12 years due to a decrease in brain "plasticity" resulting from normal neurological maturation. According to Patkowski (1980, 1990), a critical period for the learning of both L2 speech and morphosyntax ends at about the age of 15 years. The results obtained on a grammaticality judgment test administered to native Hungarian learners of English suggested to DeKeyser (2000) that:

"Somewhere between the ages of 6-7 and 16-17, everybody loses the mental equipment required for the abstract patterns underlying a human language, and the critical period really deserves its name ... It may be that the severe decline of the ability to induce abstract patterns implicitly is an inevitable consequence of fairly general aspects of neurological maturation and that it simply shows up most clearly in language acquisition (2000, pp. 518-519).

There are a number of reasons for caution in accepting the view that the age effects observed in L2 acquisition research are due to the passing of a neurologically based critical period. One reason is that at least some individuals who began learning an L2 after the putative critical period have been observed to closely resemble L2 native speakers (see, e.g., Birdsong 1992; White & Genesee 1996; Bongaerts et al. 1997).

Another reason for caution in accepting the view that age effects are due to the passing of a critical period is that individuals who began learning their L2 well *before* the putative end of the critical period have been found to differ from L2 native speakers. Several studies have shown that most early bilinguals speak their L2 with mild albeit detectable foreign accents (Flege et al. 1997; Guion et al. 2000; Piske et al. 2001). Other studies have revealed differences between early bilinguals and native speakers of the L2 in terms of the recognition of L2 words (Meador et al. 2000) and the accuracy with

which L2 vowels and consonants are produced and perceived (Pallier et al. 1997, Sebastián-Gallés & Soto-Faraco 1999, Pallier et al. 1999, Bosch et al. 2000, Flege, MacKay & Meador 1999, Piske et al. in press, MacKay, Meador & Flege 2001; MacKay, Flege, Piske & Schirru 2001; Flege et al. submitted). The observed differences between early bilinguals and L2 native speakers probably cannot be attributed to the passing of a critical period. This is because most of the early bilinguals examined in the research just cited began learning their L2 prior to the age of 7 years.

If age effects on L2 acquisition cannot be attributed to the passing of a critical period, what then might account for these effects? Broadly speaking, two other types of explanations might be offered to account for the better L2 performance of early bilinguals than late bilinguals. First, variables that are typically confounded with age in L2 acquisition studies may be responsible for the age effects, not the participants' state of neural development when they first began to learn the L2 (Flege 1987a). The variable that seems to be confounded most strongly with the age of L2 learning is the amount and quality of L2 input that is received. Another explanation (e.g., Flege 1992) is that, as the L1 system develops, it exerts an increasingly strong influence on L2 learning.

2. The importance of input

There is increasing evidence that the quantity and quality of L2 input received by an L2 learner is an important determinant of ultimate degree of attainment in an L2. Flege & Liu (2001) summarized a number of cross-sectional studies comparing groups differing in length of residence (LOR) in the United States. All had learned English as an L2 in the U.S. in adulthood. Most of the previous studies reviewed by Flege & Liu (2001) showed little or no difference between the groups differing in LOR. The literature review suggested, therefore, that additional exposure to English in adulthood leads to little or no progress in English. The lack of LOR effects may have been due to sampling error, however.

Flege & Liu (2001) compared groups of Chinese speakers differing in LOR (2 versus 7 years) on three measures of L2 learning (grammatical sensitivity to English sentences, identification of word-final English consonants, and listening comprehension). Half of the participants were enrolled as full-time students at an American university, whereas the other half of the participants had occupations that were likely to reduce the frequency of interactions with native English speakers. Students with an average LOR of 7 years obtained higher scores on all three tests than students with an average LOR of 2 years did. However, the differences between nonstudents having LORs of 2 and 7 years were non-significant in each instance, and even tended to be lower for the 7-year than the 2-year LOR group. This indicated that an increase in LOR does not, in itself, guarantee progress in learning an L2. LOR might provide a reasonable estimate of amount of L2 experience only for people (e.g., school children) who are known to be immersed in an L2-speaking environment.

Late bilinguals seem to receive less adequate L2 input than most early bilinguals. An examination of U.S. census data suggested to Stevens (1999) that age effects on immigrants' learning of English as an L2 in the U.S. might be attributed to "social and demographic considerations". For example, child immigrants are usually enrolled in a school where they interact frequently with native speakers of English, whereas adult immigrants often enter the workplace where they interact frequently with fellow native speakers of their L1. Early bilinguals are also more likely to marry L2 native speakers than late bilinguals are. Economic and social factors may well be linked to, or even cause, variation in motivation to learn the L2 well (Gardner & Lambert 1972).

Grosjean (1982, p. 195ff) questioned the assumption that "young children acquire languages more quickly and with less effort than older children and adolescents". He suggested that psychosocial factors affect L2 learning more importantly than factors such as the age of first exposure to an L2, language aptitude, and intelligence. Grosjean (1982) observed that the contexts in which languages are learned and used influence a bilingual's performance in both the L1 and the L2. He observed that the L2 may become a bilingual's dominant language if it is used more than the L1 and is needed for a wider range of everyday activities, and that the dominant language is likely to develop to a greater

extent than the non-dominant language does.

3. Confounds with age

Many factors tend to be confounded with immigrants' age of arrival (AOA) in a predominantly L2-speaking environment. These factors may, individually or collectively, offer an important advantage to early as compared to late bilinguals. For example, recent work by Jia & Aaronson (1999) provided cross-sectional and longitudinal evidence suggesting that child immigrants to the U.S. from China receive more input from native English speakers than adolescent immigrants did (see also Grenier 1984), and were more likely to become English-dominant.

Flege (1998) reviewed studies that examined 240 native Italian immigrants to Canada, and 240 native Korean immigrants to the U.S. For both groups of immigrants, AOA was inversely correlated with length of residence in North America (Italian $r = -0.44$, Korean $r = -0.42$) and self-reported use of English (Italian $r = -0.47$, Korean $r = -0.56$). That is, the later the immigrants had arrived in North America and began to learn English, the longer they tended to have lived in North America at the time of testing, and the less they tended to use English.¹ Both a relatively short LOR and an infrequent use of English might be expected to adversely affect late bilinguals' learning of an L2.

In bilinguals, amount of L1 use is inversely related to amount of L2 use, and so variation in L1 use will also be related to AOA. Flege et al. (1995a) assessed the L1 and L2 use of native Italian speakers who had immigrated to Canada from Italy between the ages of 2 and 22 years. The 240 Italian-English bilinguals had been living in Canada for an average of 32 years at the time they were tested in Ottawa. As shown in Figure 1, the participants in all 10 AOA-defined subgroups reported using English more often on average than Italian, perhaps because the Italian-speaking community in Ottawa is small. However, the size of the difference between English and Italian use varied considerably as a function of AOA. The participants who immigrated in early childhood reported using English nearly four times as much as Italian, whereas those who arrived in Canada as young adults reported using English scarcely more than Italian.

An even more striking relation between L1 and L2 use patterns and AOA was observed for 240 native Korean immigrants to the U.S. by Flege, Yeni-Komshian & Liu (1999). These authors computed the ratio of self-reported English to Korean use. A function with two linear pieces was observed when these ratios were plotted as function of AOA. The ratios decreased linearly between AOAs of 2 and 12 years, then remained constant at about 1.0 (indicating equal L1 and L2 use) for participants having AOAs of 13 to 23 years.

Recent studies have provided evidence that age-related differences in language use may exert an effect on performance in the L2. As already mentioned, the AOAs of the Korean-English bilinguals examined by Flege, Yeni-Komshian & Liu (1999) ranged from 3 to 23 years (*mean* = 12 years). These participants had been living in the U.S. for 8 to 30 years (*M* = 15 years) at the time they were tested, and had attended English-speaking U.S. schools for 0 to 19 years (*mean* = 10 years). As expected, the Korean participants' grammaticality judgment test scores decreased as AOA increased. However, when variables confounded with AOA (L1 use, L2 use, years of U.S. education, LOR) were controlled in matched subgroup analyses, the effect of AOA on the grammaticality judgment test scores became non-significant.

Other analyses carried out by Flege, Yeni-Komshian & Liu (1999) indicated that what initially appeared to be an effect of AOA on grammaticality judgment test scores could be attributed to AOA-

1 The pattern observed for groups of participants does not, of course, extend to all individuals. In a study where participants are selected solely on the basis of AOA (with a minimum LOR), some late-arriving immigrants will be found to have a relatively long LOR whereas some early-arriving immigrants will be found to have a relatively short LOR (see Flege et al. 1999, Table 8).

related differences in amount of English use and years of education in the U.S. When taken together, the results suggested that the "age" effects observed in some other studies (e.g., Johnson & Newport 1989, DeKeyser 2000) may not have been due to endogenous factors associated with maturation, such as a loss of neural plasticity. The observed effects may have been due, at least in part, to age-related differences in the contexts in which languages are learned and used (Grosjean 1982).

Flege, Yeni-Komshian & Liu (1999) found that as the Korean participants' AOA in the U.S. increased, their foreign accents in English sentences tended to become stronger. Unlike the case for the morphosyntax scores, AOA seemed to influence degree of foreign accent independently of factors that were confounded with AOA. That is, subgroups of native Korean participants who differed in AOA to the U.S., but were matched for factors that were confounded with AOA in the sample of 240 participants taken as a whole, differed significantly in their pronunciation of English sentences. Thus, whereas the findings of Flege, Yeni-Komshian & Liu (1999) argued against the existence of a critical period for the learning of L2 morphosyntax, these findings left open the possibility of a critical (or sensitive) period for L2 speech acquisition.

Early and late bilinguals differ in terms of their overall state of neural maturation when L2 learning begins (see, e.g., Bates et al. 1992). Thus the age effect on overall degree of foreign accent in English sentences observed in the Flege, Yeni-Komshian & Liu (1999) study might be taken as support for the existence of a critical period for speech learning that results from normal brain development (Scovel 1988). Although there is no evidence available that is sufficient to disprove this hypothesis, evidence is accumulating in support of alternate explanations for age effects on L2 speech learning.

Prior to the suggestion by Lenneberg (1967) that L2 acquisition might be constrained by a critical period, native versus non-native differences in L2 performance were usually attributed to cross-language "interference". Interference was usually regarded as the influence of prior learning on subsequent learning, that is, as an effect of the L1 on the L2. Grosjean (1982) suggested, however, that interference is bi-directional, and that the dominant language will influence the non-dominant language to a greater extent than the reverse. Early bilinguals who learn English as an L2 in North America tend to be dominant in the L2, whereas late bilinguals tend to remain dominant in their L1 (Jia & Aaronson 1999; Flege et al. 2001). Grosjean's observation suggests, therefore, that there might be a stronger influence of the L1 on the L2 for late bilinguals, but a stronger influence of the L2 on the L1 for early bilinguals. Grosjean also suggested (1989, 1997, Grosjean & Soares 1986) that neither language system of a bilingual can be fully deactivated. This implies that bilinguals are always likely to differ somewhat from monolinguals, even in their dominant language (Grosjean 1989).

The foreign accent findings obtained in a recent study by Yeni-Komshian et al. (2000) supported the hypotheses drawn from Grosjean's conceptualization of bilingual language organization. This study examined degree of Korean foreign accent in English sentences spoken by 240 Korean-English bilinguals living in the U.S., and degree of American English foreign accent in the same participants' production of Korean sentences. The English and Korean sentences were elicited using a delayed repetition technique, and were later rated by native English and Korean listeners, respectively. Figure 2 shows the mean ratings obtained for 10 groups of 24 bilinguals each who differed according to their AOA in the U.S. from Korea. Also shown are the mean ratings obtained for English and Korean sentences spoken by 24 monolingual speakers of English and Korean. The English sentences spoken by all 10 groups of bilinguals—even those who had arrived in the U.S. as young children—received significantly lower ratings than the English monolinguals' sentences did. This replicated a finding obtained by Flege et al. (1997) in showing that even early bilinguals are apt to speak their L2 with a foreign accent.

Even more importantly, the foreign accent ratings obtained for the Korean-English bilinguals' Korean and English sentences showed a significant negative correlation ($p < 0.01$). The later the bilinguals had first arrived in the US, the stronger their Korean foreign accents in English sentences tended to be. Conversely, the earlier the Korean-English bilinguals had arrived in the U.S., the stronger were their American English foreign accents in Korean sentences.

To assess the effect of language dominance on pronunciation, a re-analysis of data obtained by Yeni-Komshian et al. (2000) was carried out. This involved estimating dominance through an examination of self-reported proficiency in the L1 and L2. The Korean-English bilinguals used 5-point scales to self-rate their ability to pronounce English and Korean, their ability to read and write English and Korean, their ability to remember the pronunciation of English and Korean words, and their knowledge of English and Korean grammar. A ratio of the mean ratings obtained in English compared to Korean was computed for each participant. The ratio obtained for the 72 bilinguals who had arrived in the U.S. prior to the age of 8 years ($mean = 2.54$, $range: 1.06$ to 5.0) was significantly above 1.0, $t(1) = 13.39$, $p < 0.01$, indicating that these early bilinguals were dominant in English. The ratio obtained for the 72 bilinguals who had arrived in the U.S. after the age of 16 years ($mean = 0.71$, $range: 0.33$ to 1.00) was significantly below 1.0, $t(1) = -13.43$, $p < 0.01$, indicating dominance in Korean.

The foreign accent ratings obtained for the 240 Korean-English bilinguals examined by Yeni-Komshian et al. (2000) were converted to z-scores. The early bilinguals obtained significantly lower z-scores for Korean than English sentences, $F(1,142) = 377.0$, $p < 0.001$, whereas the late bilinguals obtained significantly *higher* scores for Korean than English sentences, $F(1,142) = 377.0$, $p < 0.001$. This supported the hypothesis (see above) that late bilinguals' L1 will have a greater effect on their L2 rather than the reverse whereas, for early bilinguals, the L2 will influence the L1 to a greater extent than the L1 influences the L2.

4. Phonetic interactions

The results shown in Figure 2 suggest the possibility that correlations between AOA and degree of foreign accent might be due to changes in how the L1 and L2 interact rather than (or in addition to) a maturationally-induced loss in the capacity for learning speech. This observation forms the cornerstone of the Speech Learning Model, or SLM (Flege 1995), which aims to account for changes across the life span in speech learning.

The SLM starts with the controversial notion that the processes and mechanisms that children use when establishing the sound system of the L1 remain intact across the life span, and remain accessible for use in L2 learning. This does not represent the claim, however, that child and adult learners will ultimately achieve the same proficiency in their L2. This is because other factors will prevent the intact speech learning mechanisms from developing long-term memory representations for vowels and consonants that are identical to those developed for a single language by monolinguals. The primary reason why most L2 learners continue to differ from monolingual native speakers of the L2 may be that they continue to speak their L1, which is likely to influence the L2. The SLM posits that the phonic elements making up the L1 sound system and the phonic elements comprising the L2 system (either newly established categories, or adaptations of L1 categories) exists in a "common phonological space", and so will mutually influence one another.

There is evidence (e.g., Hazan & Barrett 1999) that the L1 phonetic system develops slowly through childhood and into adolescence. According to the SLM, as L1 phonetic categories develop, they become more likely to perceptually "assimilate" (e.g., Best 1995) the vowels and consonants encountered in an L2. If someone learning an L2 continues to judge an L2 vowel or consonant to be an instance of an already-established L1 vowel or consonant category, the L2 vowel or consonant is said to have been "equated" with the L1 speech sound. The SLM proposes that equivalence classification may prevent new categories from being created for certain L2 vowels and consonants, although the *capacity* for creating new categories remains intact across the life span. Another important determinant of whether new categories will be created is the perceived phonetic distance of L2 vowels and consonants from the closest L1 speech sound (vowel or consonant). By hypothesis, the more phonetically distant from the closest L1 speech sound an L2 speech sound is perceived to be, the more likely it is that an L2 learner—adult or child—will establish a new category for the L2 speech sound.

The SLM (Flege 1995) proposes two specific mechanisms through which the phonetic categories comprising the L1 and L2 phonetic subsystems will interact: category assimilation and category dissimilation. Both are hypothesized to exert effects on phonetic categories in the L1 and L2. Which of the two mechanisms operates is thought to depend on whether category formation has, or has not, taken place.

By hypothesis, the L1 and L2 phonetic systems will interact through the mechanism of category assimilation when category formation has been blocked. In such instances, the L2 learner may initially produce the L2 speech sound just as if it were the corresponding L1 speech sound, that is, without any modification. However, if the L2 sound differs audibly from the L1 sound with which it has been equated, modification is expected. The SLM proposes that the single long-term memory representation that is used for processing instances of an L1 phonetic category and its counterpart in the L2 will gradually evolve, yielding a "merged" L1-L2 category that reflects L1 and L2 phonetic input. Depending on the nature of the input that has been received over the course of a bilingual's lifetime, the merged category may resemble more closely the long-term representation of either L1 monolinguals or L2 monolinguals.

It is hypothesized that the L1 and L2 phonetic systems will interact through the mechanism of category dissimilation when a new category is established for a speech sound that is found in the L2 but not the L1. As L2 learners add new categories, their combined L1-L2 phonetic space becomes more crowded than that of monolingual speakers of either the L1 or the L2. Phonetic research has shown that the phonic elements making up the phonetic space of human languages tend to disperse in order to maintain phonetic contrast (see de Boer 2000 for discussion). The SLM proposes that this also occurs for the phonic elements making up the L1-L2 phonetic space of individual bilinguals, who strive to maintain contrast both within and between the phonetic categories comprising their two phonetic subsystems. This may cause a newly established L2 category to "deflect away" (Bohn & Flege 1992) from the nearest L1 category, and vice versa. If this happens, neither the L1 category nor the new L2 category will be identical to the categories possessed by monolinguals.

The claim that bilinguals attempt to maintain phonetic contrast between the speech sounds used to produce both L1 and L2 words is controversial. One might assume that if an L1 and an L2 speech sound were close to one another in phonetic space, they could be differentiated (if confused) by listeners through an identification of which language was being spoken. Elman et al. (1977) found that some bilingual listeners made perceptual adjustments of this kind. However, as Grosjean (1982) has noted, bilinguals are apt to use both of their languages in rapid succession. Distinguishing the phones of the L1 and L2 phonetic subsystems might serve to facilitate lexical access, especially when bilinguals search both the L1 and L2 lexicons in the process of accessing a word.

The interaction between the L1 and L2 phonetic sub-systems has been investigated in a number of studies carried out within the framework of the SLM (Flege 1995). The purpose of the remaining portion of this chapter is to describe studies that have examined language interaction through the mechanisms of phonetic category assimilation and dissimilation. Two studies showing the operation of category assimilation will be presented, followed by two studies showing the operation of category dissimilation.

5. Phonetic category assimilation

A number of investigators have carried out "perceptual assimilation" experiments to assess the degree of perceived cross-language phonetic distance between speech sounds drawn from two languages. In such experiments (e.g. Schmidt, 1996), participants typically identify L2 speech sounds that have been produced in a single phonetic context in terms of the abstract phonetic categories of their L1. They then rate the L2 speech sounds for degree of goodness of fit to the selected L1 categories. However, the literature on L2 speech acquisition has not yet converged on the most appropriate method for gauging cross-language phonetic distance. One complicating factor is that certain L1 and

L2 sounds that are likely to be judged to be "the same" speech sound may not occur in the same range of phonetic contexts in both languages. Even if they did, patterns of allophonic variation may differ cross-linguistically. As a result, it remains uncertain at what level of analysis (e.g., phonemes, position-sensitive allophone, "major" allophones, context-sensitive allophones) the phonic elements of a bilingual's two languages are perceptually related to one another (see Strange 1999 and Strange et al. 2001 for discussion).

As mentioned, the SLM proposes that phonetic category assimilation will occur when category formation for an L2 speech sound has been blocked. This is thought to occur when the L2 learner continues indefinitely to judge the instances of an L2 category to be instances of an L1 category. By hypothesis, the likelihood of phonetic category formation is inversely related to degree of perceived cross-language phonetic distance. One would expect phonetic category assimilation to operate when the L1 and L2 possess speech sounds that are close to one another in phonetic space, but are not physically identical to one another. In such instances, the perceived phonetic similarity of the L1 and L2 speech sounds would be too great for phonetic category formation to occur; yet the cross-language phonetic differences would be auditorily detectable.

Importantly, the SLM claims that the blockage of category formation does not prevent phonetic learning from taking place, for even late bilinguals remain sensitive to (what are for them) sub-categorical cross-language phonetic differences. (For evidence of this, see e.g., Flege & Hammond 1982, Munro et al. 2000, Werker & Logan 1985, Sharma & Dorman 2000.) In the absence of category formation, bilinguals are predicted to develop a "merged" L1-L2 category that subsumes the properties of phonetically distinct L1 and L2 speech sounds that have been perceptually equated. By hypothesis, a merged category will be used to identify and produce instances of the perceptually equated L1 and L2 speech sounds.

Category assimilation has been observed in two studies involving the production and perception of stop consonants. Flege (1987b) examined the production of /t/ in French and English words by English-French and French-English bilinguals. The English-French bilinguals were American women who had begun to learn French in adulthood, and had been living in Paris for an average of 12 years. The French-English bilinguals were French or Belgian women who had begun to learn English in adulthood and had lived in Chicago for an average of 12 years. Both groups of bilinguals read lists of French and English phrases of the form "Tous les X" and "Two little X" (where X = French or English nouns, as appropriate). French and English monolinguals produced just the French and English phrases, respectively. Voice onset time (VOT) values was measured in the utterance-initial /t/ tokens.

As expected, the English monolinguals produced /t/ with long-lag VOT values, whereas the French monolinguals produced /t/ with short-lag VOT values.² The question of interest was whether the late bilinguals would fully accommodate the phonetic difference between French /t/ and English /t/. The VOT values shown in Figure 3 show that they did not. These data are instead consistent with the hypothesis that merged categories may develop in an L2.

First, we see evidence that phonetic learning had taken place in the L2. The French-English bilinguals produced English /t/ with longer average VOT values than the French monolinguals produced in French /t/. The fact that they did not produce English words with an unmodified French /t/ suggests that they had detected the difference between the short-lag stops characteristic of French and the long-lag stops characteristic of English. However, the VOT values the French-English bilinguals produced in English /t/ were not as long as the VOT values produced by the English monolinguals. Conversely, the English-French bilinguals produced French /t/ with shorter VOT values than the English

2 The long-lag VOT values produced by two French monolinguals were deleted when the mean values shown in Figure 3 were computed. These participants apparently accommodated to the English-accented French spoken by the experimenter who elicited the production data.

monolinguals produced in English stops. However, they produced longer VOT values in French /t/ than the French monolinguals did. In other words, both groups of bilinguals phonetically approximated, but did not achieve, the VOT norm for /t/ in their L2.

Second, we see evidence in Figure 3 that learning an L2 influenced how the bilinguals produced /t/ in their L1 (French or English). The French-English bilinguals produced French /t/ with longer average VOT values than the French monolinguals did (i.e., they produced French /t/ with partially English-like VOT values). Conversely, the English-French bilinguals produced English /t/ with shorter VOT values than English monolinguals did (i.e., they produced English /t/ with partially French-like VOT values).

Taken together, these results suggest that the late bilinguals examined by Flege (1987b) detected cross-language phonetic differences between the /t/s of their two languages but nevertheless did not establish a new phonetic category for the /t/ of their L2. As a result, the bilinguals' existing category representation for /t/ seems to have evolved to reflect a two-language source of input. That is, the bilinguals' merged /t/ categories may have reflected the properties of the French /t/s and English /t/s they had heard, so that it differed from the phonetic category representations of both English and French monolinguals. The exact nature of these representations presumably reflected the array of input values they had experienced over their lives, perhaps with more recently encountered tokens being weighted more heavily than tokens encountered in the distant past (Sancier & Fowler 1997).

A recent study by MacKay, Flege, Piske & Schirru (2001) provided evidence of phonetic category assimilation for both early and late bilinguals. The four groups of Italian-English bilinguals who participated were selected on the basis of their AOA in Canada (early: 2-13 years; late: 15-26 years) and how much they continued to use Italian (low-use: 1-15%, high-use: 25-80%). The study focused on the production and perception of English /b d g/ in word-initial position. In English, /b d g/ are usually realized with short-lag VOT values that are similar to those for Italian /p t k/. In Italian, on other hand, /b d g/ are realized as pre-voiced stops (i.e., with lead VOT values).

There were several *a priori* reasons to think that native Italian speakers—even those exposed to English as children—will not establish categories for English /b d g/. First, realization of English /b d g/ with the lead VOT values that are typical for Italian would be acceptable in English. There would therefore be no communicative pressure for Italian-English bilinguals to establish new categories for English /b d g/ (Port & Mitleb 1983, p. 223). Second, stop consonants in the world's languages are realized with one of three modal VOT categories: lead (pre-voiced), short-lag, and long-lag. Keating (1984, p. 224) proposed that there may only be as many phonetic categories in languages as there are "contrasting phonetic types". The same appears to hold true for individual bilinguals (see Flege & Eefting 1988). Finally, bilinguals usually identify short-lag stops in much the same way in their L1 and L2 (e.g., Elman et al. 1977; Bohn & Flege 1993). The establishment of short-lag categories for English /b d g/ is therefore likely to be pre-empted perceptually by existing Italian categories (viz., those for /p t k/).

MacKay, Flege, Piske & Schirru (2001) found that both of two groups of late bilinguals (Late-high, Late-low) and early bilinguals who often used Italian (Early-high) pre-voiced English /b/ significantly more often than English monolinguals did. The difference between early bilinguals who used Italian seldom (Early-low) and the English monolinguals was non-significant, however. Interestingly, all four groups of bilinguals pre-voiced /b/ in English less often than is typical for Italian (as shown by the speech of a group of Italian monolinguals).

MacKay, Flege, Piske & Schirru (2001) also examined the identification of natural tokens of /b d g/ that had been produced in the initial, medial, and final positions of English words. The word-initial /b d g/ tokens were realized with short-lag VOT values that resembled those typical for Italian /p t k/. All four groups of Italian-English bilinguals made more errors identifying the /b d g/ tokens (hearing them as /p t k/) than English monolinguals did. However, only the two groups of late bilinguals differed significantly from English monolinguals. A comparison of the pattern of errors observed in the three

word positions suggested that the late bilinguals' identification errors were due to the lack of pre-voicing in the word-initial /b d g/ tokens.

Another experiment carried out by MacKay, Flege, Piske & Schirru (2001) examined Italian-English bilinguals' production of /b d g/ in Italian words. It provided evidence for the operation of phonetic category assimilation. A positive correlation was found to exist between the bilinguals' production of stops in English and Italian. The less frequently the bilinguals fully pre-voiced English /b d g/, the less frequently they tended to do so when producing stops in Italian words. This finding, which is analogous to the results of Flege (1987b) for voiceless stops, was consistent with the view that the Italian-English bilinguals had not established separate phonetic categories for English /b d g/. If they had done so, there would be no reason to expect their production of L1 stops to change, nor for them to have only partially approximated the English phonetic norm for /b d g/. The results therefore suggested that the Italian-English bilinguals produced and perceived /b/ in both Italian and English using a single phonetic category in which the properties of English /b/ and Italian /b/ had been merged.³

Of the four groups of bilinguals examined, the group whose productions of English /b/ were most English-like (i.e., the Early-low group) also showed the greatest influence of English on their production of Italian /b d g/. MacKay, Flege, Piske & Schirru (2001) suggested that differences between the four groups of bilinguals arose not from the operation of different mechanisms but, rather, from differences in the phonetic input the bilinguals had received over the course of their lives. For example, the early bilinguals had lived longer in Canada than the late bilinguals had (*means* = 41 vs. 30 years), and they had received more education in English-speaking Canadian schools than the late bilinguals had (*means* = 13 vs. 2 years). The early bilinguals also reported using Italian less overall than the late bilinguals did (*means* = 25% vs. 31%). The early bilinguals may therefore have used English more often with native English speakers than the late bilinguals had, and they may have been exposed to Italian-accented English less often than the late bilinguals had been.

6. Phonetic category dissimilation

According to the SLM, the phonetic category that a bilingual establishes for an L2 speech sound may differ from a monolingual's category if it dissimilates from categories not found in a monolingual's system. When category dissimilation operates, it increases the phonetic difference between the realizations of a newly established L2 category and the realizations of the closest L1 category. This means that a bilingual's productions of the neighboring L1 and L2 speech sounds should differ more than the productions of those speech sounds by monolingual speakers of the L1 and L2. Mack (1990) obtained VOT evidence in a case study of a bilingual child which suggested the operation of category dissimilation. Two other studies have provided more compelling evidence for the operation of this mechanism.

Flege & Eefting (1987) obtained evidence of category dissimilation in a study examining Spanish-English bilingual children and adults. The participants' productions of /p t k/ in the initial position of Spanish and English words were examined. These stops were examined because /p t k/ are realized with short-lag VOT values in Spanish but with long-lag VOT values in English. The bilinguals were tested in Mayaguez, Puerto Rico, where they had learned English at a local bilingual school in which

3 The finding obtained in a recent vowel perception experiment also suggested the operation of category assimilation. Flege et al. (1999) examined the categorial discrimination of the contrasts between four pairs of English vowels (/æ/-/ʌ/, /ʌ/-/ɒ/, /i/-/ɪ/, /u/-/ʊ/) and three pairs of Italian vowels (/u/-/o/, /e/-/a/, /u/-/i/). Late bilinguals with an average AOA in Canada of 19 years discriminated all four of English vowels less accurately than a group of early bilinguals with an average AOA of 7 years did. The late bilinguals also discriminated the Italian vowels less accurately than the early bilinguals did. One possible interpretation of this finding is that, in the absence of category formation for English vowels, the late bilinguals' Italian vowels evolved to reflect the properties of English vowels they were adapted to process.

English was used as a language of instruction. Some of the teachers, and a few of the students in this bilingual school were native speakers of English. Both the adult and child bilinguals were early bilinguals inasmuch as their first exposure to English occurred when, as children, they began attending the bilingual school.

The two groups of Spanish-English bilinguals were compared to age-matched groups of Spanish monolinguals (or, more accurately, “near” monolinguals). The monolingual children attended a public school in Mayaguez where only Spanish was used. The monolingual adults were students at the University of Mayaguez who had studied English as a foreign language for several years in high school and at the university. None of these individuals could carry on a simple conversation in English. The bilinguals were also compared to monolingual English children and adults (pupils at a parochial school and students at a university located in Birmingham, Alabama, respectively). The bilinguals were asked to read lists of Spanish and English words that began with the phonologically voiceless stops /p t k/, whereas the monolingual participants read a list of words in their native language only.

Figure 4 shows the mean VOT values measured in stops produced by monolingual speakers of Spanish and English. Each mean value was based on 150 measurements (10 participants per group x 3 stop consonants x 5 words). As expected, the English monolinguals produced /p t k/ with significantly longer VOT values than the Spanish monolinguals did ($p < 0.01$). Also, the adults were found to have produced /p t k/ with significantly longer VOT values than the children did ($p < 0.01$). The lack of a Language x Age interaction ($p > 0.10$) indicated that the adult versus child difference was comparable in Spanish and English despite the substantial difference in how /p t k/ are realized phonetically in those languages. This finding supported the SLM's assumption that representations used to guide the production of phonetic segments in the L1 continue to develop slowly over time.

Figure 5 shows the mean VOT values in Spanish and English stops produced by the child and adult bilinguals. (Once again, each mean was based on 150 VOT measurements.) Both the child and the adult bilinguals produced /p t k/ with significantly longer VOT values in English words than in Spanish words. The lack of a significant Age x Language interaction suggested that the child and adult bilinguals produced comparable cross-language differences in VOT.

Both groups of early bilinguals produced English stops with somewhat shorter VOT values than age-matched English monolinguals did. This might be interpreted to mean that the early bilinguals were only partially successful in learning to produce English /p t k/. However, Flege (1991) found that early bilinguals living in the U.S. produced English stops with VOT values that matched those produced by age-matched English monolinguals. The differing results obtained for the early Spanish-English bilinguals tested in Puerto Rico (Flege & Eefting 1987) and in the U.S. (Flege 1991) may therefore have been due to differences in input. That is, the early bilinguals tested in Puerto Rico, but not those tested in the U.S., may have differed from age-matched English monolinguals because they were more likely than the bilinguals tested in the U.S. to hear English spoken with a Spanish accent (including stops produced with VOT values that are too short for English).

Figure 6 provides evidence of dissimilation. This figure shows the mean VOT values in Spanish /p t k/ tokens produced by age-matched Spanish monolinguals and early Spanish-English bilinguals in Puerto Rico. Both adult and child bilinguals produced Spanish /p t k/ with significantly shorter VOT values than the Spanish monolinguals did. By hypothesis, the bilinguals modified their production of Spanish /p t k/ to make it more distinct phonetically from the categories they had established later in life for English /p t k/. The lack of a significant Age x Language Status (monolingual vs. bilingual) interaction suggested that both the child and adult bilinguals had shortened the VOT values in Spanish /p t k/ to a comparable extent.

Independent evidence that the early Spanish-English bilinguals had established new categories for English /p t k/ was provided in a follow-up study by Flege & Eefting (1988). In this study, the bilinguals and monolinguals described earlier were asked to imitate as accurately as possible the

consonant-vowel syllables making up a synthetic VOT continuum. The stimuli had VOT values ranging from pre-voiced to long-lag, and so included tokens resembling pre-voiced Spanish /d/, short-lag tokens of Spanish /t/ and English /d/, and long-lag tokens of English /t/.

The Spanish and English monolinguals did not imitate the VOT values of all of the stimuli with equal accuracy. Most stops produced by the Spanish monolinguals had the pre-voiced (lead) VOT values that are typical for Spanish /d/ or the short-lag VOT values that are typical for Spanish /t/. Conversely, most stops produced by the English monolinguals had the short-lag VOT values that are typical for English /d/ or the long-lag VOT values that are typical for English /t/. Both groups of early bilinguals, on the other hand, produced stops having VOT values falling into all three modal VOT ranges (lead, short-lag, long-lag). Given that only a short interval was available for imitating each CV stimulus, this supported the view that the early bilinguals had established phonetic categories for English /p t k/.

Dissimilation effects analogous to the kind that have been proposed by the SLM for bilinguals were observed in a study comparing vowels in dialects having somewhat different vowel inventories (Moulton 1945). Flege et al. (submitted) obtained the first evidence of category dissimilation in L2 vowel production in a study examining Italian-English bilinguals' production of English /e^ɾ/. This vowel was of interest for three reasons. Flege & MacKay (submitted) found that native Italian students with little English-language experience usually classified English /e^ɾ/ tokens as instances of Italian /e/. Flege et al. (submitted) confirmed that English /e^ɾ/ is produced with considerably more movement than Italian /e/ is. Finally, Flege, MacKay & Meador (1999) observed differences in the ability of Italian-English bilinguals to discriminate English /e^ɾ/ from Italian /e/ tokens. Of the four groups of Italian-English bilinguals who were examined (Early-low, Early-high, Mid-high, Late-high), only the participants in an Early-low group discriminated /e^ɾ/-/e/ at a significantly above-chance rate in a categorial discrimination test. This finding was interpreted to mean that more participants in the Early-low group than in the other three groups had established a phonetic category for English /e^ɾ/. It led to the prediction tested by Flege et al. (submitted), viz. that more Early-low participants than participants in Early-high, Late-low and Late-high groups would show an effect of category dissimilation. The predicted effects of category dissimilation was the production of English /e^ɾ/ with more movement than observed in the production of /e^ɾ/ by native English speakers.

The bilinguals examined by Flege et al. (submitted) were assigned to one of four groups based on AOA (early bilinguals: 2-13 years, late bilinguals: 15-26 years) and amount of continued L1 use (low-use: 1-15%, high-use: 25-85%). Aurally presented English words that had been spoken by native English speakers were repeated following a filled delay. The participants' repetitions of the words were digitized, then presented to native English-speaking listeners, who rated them for accuracy as instances of their intended category. (Each vowel was presented in a separate block.)

As expected from previous studies (Flege et al. 1997, Piske et al. 2001, Piske & MacKay 1999, Guion et al., 2000, Meador et al. 2000, MacKay, Meador & Flege 2001, Piske et al. in press), both AOA and L1 use affected the bilinguals' production of English vowels. The early bilinguals produced certain English vowels more accurately than the late bilinguals did; and the bilinguals who used Italian seldom produced certain English vowels more accurately than the "high-use" bilinguals who used Italian relatively often did.

Neither the vowels spoken by participants in the Early-low or in the Early-high group were found to differ significantly from the vowels spoken by native English speakers. However, an acoustic analysis by Mack (1989) revealed differences between vowels spoken by early bilinguals and monolingual native speakers of English. Also, theoretical perspectives lead to the expectation that subtle differences will exist between early bilinguals and native speakers of the L2 (Paradis 1978, Mack 1989, Grosjean 1989, 1997, 1999, Flege 1995). Thus a question of interest was whether an acoustic analysis of /e^ɾ/ would reveal differences between the early Italian-English bilinguals and English

monolinguals.

Flege et al. (submitted) used the Kay Elemetrics Multi-Speech program to make spectral measurements of /e^ɪ/ tokens. A beginning and an ending location in the "vowel" portion of each digitized word (located 20% and 80% into the vowel interval) were identified from time domain waveforms and spectrographic representations. The auto-correlation method of linear predictive coding (LPC) analysis was used to estimate the frequency of the first two vowel formants (F1, F2) at each location. The following procedure was used to estimate the amount of tongue movement in the production of each token. To begin, the frequency values in Hertz were converted into bark units (Syrdal & Gopal 1986) because there were slightly different numbers of male and female subjects in the various groups. The position of each beginning and ending vowel quality in a high-low dimension was estimated by subtracting the values for F0 from the F1 values at the same measurement location (F1-F0 in barks). Positions in the front-back dimension were estimated by subtracting the F1 values from the F2 values (F2-F1 in barks). The Euclidean distance between points defined by the beginning F1-F0 and F2-F1 values, and the ending F1-F0 and F2-F1 values, was then calculated for each token. These scores provided a rough estimate of amount of tongue movement during the production of /e^ɪ/.

Figure 7 shows the location in a two dimensional acoustic space (high-low vs. front-back) of the mean beginning and ending values produced in English /e^ɪ/ by the four groups of Italian-English bilinguals and a group of native English speakers. The participants in all five groups produced /e^ɪ/ with a similar beginning vowel quality. However, the ending vowel quality values of the five groups differed substantially. Participants in the Late-high group produced an ending vowel quality that was lower and farther back in the vowel space than the NE speakers did. Conversely, the Early-low participants produced an ending vowel quality for /e^ɪ/ that was higher and farther forward in the vowel space than the NE speakers did.

An ANOVA examining the Euclidean distance values yielded a significant main effect of Group ($p < 0.01$). A Tukey's post-hoc test revealed that the participants in the Early-low group produced /e^ɪ/ with significantly larger Euclidean distance values—and so more tongue movement—than the participants in the native English and the Late-high groups did ($p < 0.05$). No other between-group differences reached significance. The same finding was obtained when variation in the duration of the vowel was controlled for statistically in an ANCOVA.

These findings suggested that many Early-low participants produced English /e^ɪ/ with even more tongue movement than the NE speakers did because they had established a phonetic category for English /e^ɪ/ and then attempted to maintain contrast between their English /e^ɪ/ and Italian /e/ categories. The difference between the four groups of bilinguals was interpreted to be the result of how many of the 18 participants in each bilingual group had established a phonetic category for /e^ɪ/, and thus showed an effect of phonetic dissimilation.

The conclusion just offered is consistent with the results of a study by Flege & MacKay (submitted). These authors examined the categorial discrimination of nine pairs of English vowels by the four groups of Italian-English bilinguals who participated in the Flege et al. (submitted) study. Both AOA and L1 use affected the bilinguals' discrimination of English vowels. The Early-low group obtained the highest discrimination scores and the Late-high group obtained the lowest scores. Bilingual participants were credited with category formation for English vowels if they obtained near-perfect scores resembling those obtained for native English speakers for the contrast between certain pairs of English vowels. Significantly more early than late bilinguals were so credited; and there was a non-significant trend for more low-use than high-use participants to be credited with category formation.

7. Conclusions

A number of studies have shown that earlier is better as far as the acquisition of an L2 is concerned. "Age" effects have been observed, for example, in the acquisition of L2 morphosyntax (e.g., Patkowski 1980, 1990, DeKeyser 2000) and the pronunciation of an L2 (e.g., Flege et al. 1995a). In studies examining immigrants to North America, the age of learning an L2 (English) has been indexed by the AOA in a predominantly L2-speaking environment. A recent study examining Korean immigrants to the U.S. (Flege, Yeni-Komshian & Liu, 1999) showed that age effects on the acquisition of English morphosyntax, but not age effects on L2 pronunciation, disappeared when factors confounded with AOA were controlled. This raised the issue of whether the acquisition of L2 speech is constrained by a critical period that results from normal neurological maturation (e.g., Scovel, 1988).

Critical periods for the learning of environmentally important events and stimuli are defined by an onset and an offset (Bornstein 1989). As mentioned in the introduction, a problem for the view that successful L2 speech acquisition is limited by a critical period is that the onset and offset of the putative critical period has not yet been defined. A few late bilinguals manage to perform in a native-like fashion in an L2 learned after puberty. A number of other studies have demonstrated that early bilinguals who began learning their L2 well before the end of a putative critical period often differ from individuals who are monolingual native speakers of the L2.

This chapter provided a discussion of two other potential explanations for the age effects that have been observed in studies examining immigrants to North America. The first potential explanation is that immigrants who arrive after the end of the putative critical period may not receive the kind of input that is needed for successful L2 speech learning. Early but not late bilinguals tend to inhabit an L2-rich environment. Early bilinguals are usually enrolled in schools in which the L2 is used as the sole language of instruction soon after their arrival, and often become dominant in the L2 within a few years (Jia & Aaronson 1999). Late bilinguals, on the other hand, tend to receive far less education in L2-speaking schools than early bilinguals do, and they tend to maintain the L1 as their dominant language. This means that AOA tends to be positively correlated with amount of L1 use and negatively correlated with amount of L2 use. A number of studies have shown that a frequent continued use of the L1 is associated with relatively poor performance in the L2 (e.g., Flege, MacKay & Meador 1999, Meador et al. 2000, Piske et al. 2001). This demonstrates that language use exerts an important influence on L2 speech learning. It should be noted, however, that the view offered here regarding the importance of input stands in contrast to the conclusion drawn recently by DeKeyser (2000), who wrote that:

"Input differences are not a good explanation for age effects, because it is precisely in the linguistic domains where input varies least—phonology—that the age effects are most readily apparent, and it is at the stage where the comprehensibility of input should be the least problematic—in the later stages of acquisition—that adults clearly perform worse than children (p. 519)."

The second potential explanation for age effects discussed in this chapter is a change with increasing age in the nature of L1-L2 interactions. According to the SLM (Flege 1995), L1 vowel and consonant categories become more powerful attractors of the vowels and consonants encountered in an L2 as they develop through childhood and into adolescence. This makes it ever more likely, as the L1 phonetic system develops (and the L2 learner matures, more generally), that category formation will be blocked. There is evidence, however, that the capacity for category formation remains intact across the life span (Flege & MacKay, submitted), especially for L2 speech sounds that are judged to be phonetically distant from the closest L1 category.

This chapter reviewed studies demonstrating the existence of bi-directional interactions between phonetic segments found in the L1 and L2 subsystems. Findings such as these indicate that the L1 and L2 subsystems do not exist in isolation from one another. According to the SLM, the nature of interactions between the phonetic categories comprising the L1 and L2 phonetic subsystems depends

on whether category formation does, or does not, occur. The chapter reviewed two instances of both phonetic category assimilation (which occurs when category formation is blocked) and phonetic category dissimilation (which occurs when new categories are established for L2 speech sounds). The mechanism of phonetic category assimilation yields merged L1-L2 categories. Such categories are used to process L1 and L2 speech sounds that continue to be perceived as instances of a single category. The merged categories reflect the phonetic properties of L1 and L2 speech sounds that have been perceptually equated. The mechanism of phonetic category dissimilation, on the other hand, yields L1 and L2 categories that are adjacent to one another in phonetic space, but have deflected away from one another to preserve phonetic contrast.

Additional research is needed to clarify the role of age-related variations in L2 input and changes in the nature of L1-L2 interactions on L2 speech acquisition. A number of recent studies have relied on self-reports of percentage L1 and L2 use. Better methods are needed to quantify language use patterns and, perhaps more importantly, to determine how much L2 input is received from non-natives rather than from native speakers of the L2. One crucial hypothesis of the SLM (Flege, 1995) that has so far gone untested is that category formation becomes less likely with increasing age because, as phonetic categories of the L1 develop, they become more powerful attractors of L1 vowels and consonants (but see Walley & Flege 2000).

It will be important to determine the relation between amount (and/or kind) of L2 input and category formation. Are categories formed only when a substantial amount of input has been received in a short period of time? When a large lexicon containing many potentially confusable minimal pairs has been developed? Or just for bilinguals who often switch rapidly between their L1 and L2 in conversations with other bilinguals?

Another important question that must be addressed in future research is whether category formation for an L2 speech sound always precipitates phonetic category dissimilation, thereby yielding production patterns that differ from those observed for monolingual speakers of both the L1 and the L2. One can envisage the possibility of an L2 sound that is so distant in the phonetic space from the closest L1 category that a category established for it would not influence realizations of the L1 category. If category dissimilation operates whenever bilinguals establish a new L2 category, and additional evidence shows that category formation occurs frequently in L2 speech acquisition (Flege & MacKay, submitted), it would provide a mechanism underlying the claim (e.g., Grosjean 1989, 1999) that there can be no "perfect" bilinguals who perform exactly like monolinguals in both of their languages.

Finally, it is uncertain at present how much variance in L2 speech performance will ultimately be accounted for by the three factors discussed in this chapter: neurological maturation, age-related variations in input, and changes in the nature of the interactions between phonic elements in the L1 and L2 phonetic subsystems. Perhaps all three will prove to be important. However, the latter two factors (input and interaction effects) are more directly observable than are changes in how the brain encodes the auditory information associated with speech and the complex muscle contractions that drive speech production. The most productive research strategy in the coming years may therefore be to focus on quantifying the effects of variation in L2 input and changes in L1-L2 interactions on L2 speech learning. The goal here would be to determine how much variance in L2 performance can be accounted for by these two factors. Should any variance remain unaccounted for, it might then be attributed to neurological maturation.

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Figure 1. Mean self-reported L1 (Italian) and L2 (English) use by 10 groups of 24 Italian-English bilinguals who differed according to age of arrival in Canada from Italy. From Flege, Munro & MacKay (1995a).

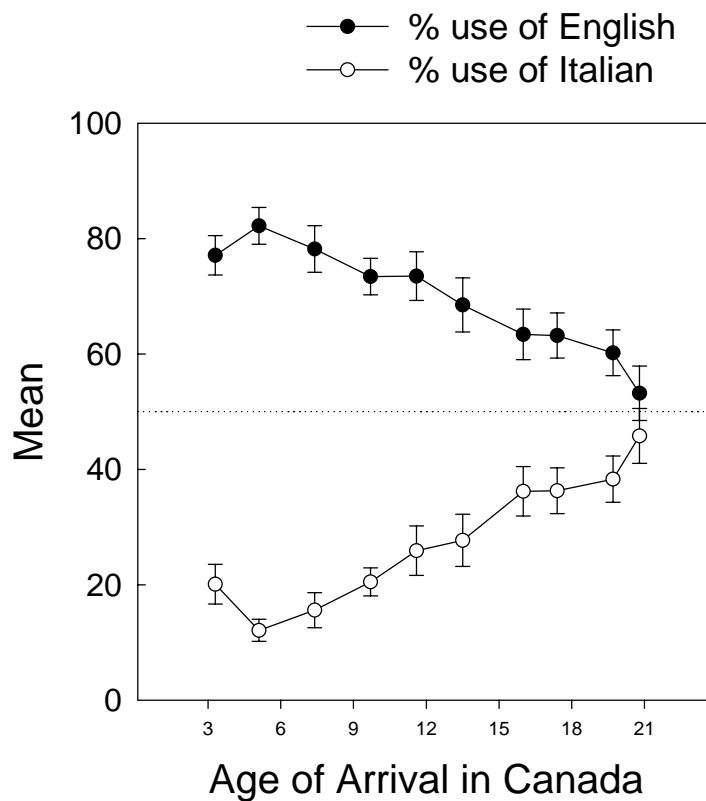


Figure 2. Mean degree of foreign accent in English sentences produced by 10 groups of 24 Korean-English bilinguals (unfilled circles) and 24 native English monolinguals (unfilled square), and in Korean sentences produced by the same 240 Korean-English bilinguals (filled circles) and 24 Korean monolinguals (filled square). The brackets enclose ± 1 SE. From Flege, Yeni-Komshian & Liu (1999).

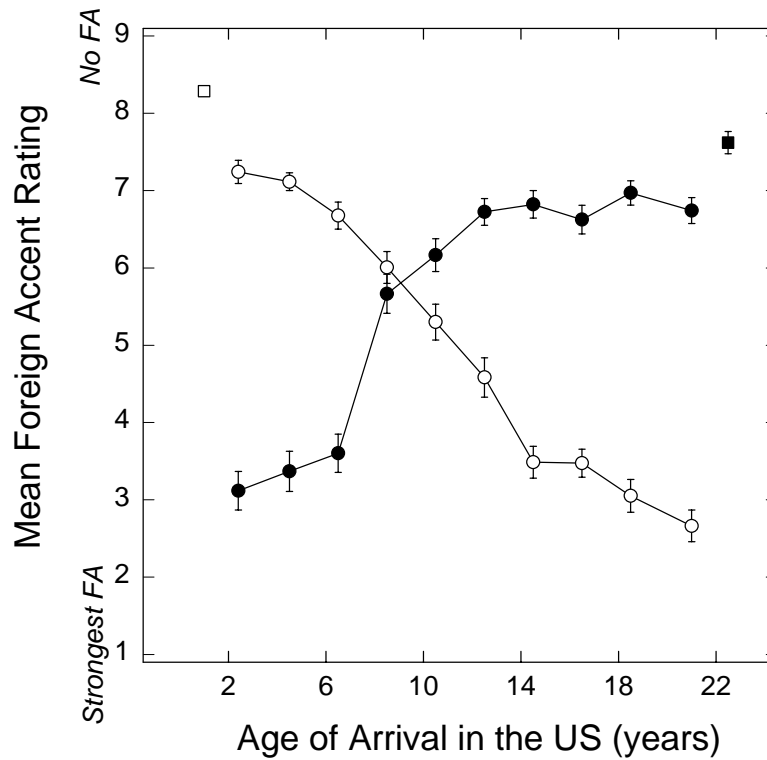


Figure 3. The mean VOT values in /t/ tokens in the initial position of French and English words spoken by late French-English bilinguals living in the U.S. and late English-French bilinguals living in France. The mean VOT values obtained for English and French monolinguals are represented by dashed lines. From Flege (1987b).

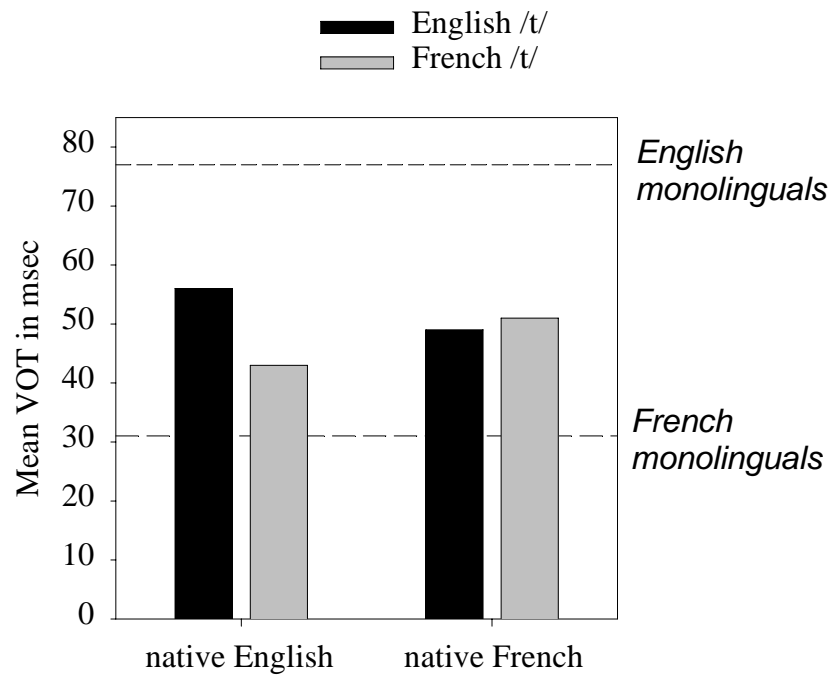


Figure 4. The mean VOT in tokens of /p t k/ produced in the initial position of Spanish words spoken by monolingual Spanish children and adults living in Puerto Rico, and in the initial position of English words spoken by monolingual English children and adults living in Alabama. From Flege & Eefting (1986).

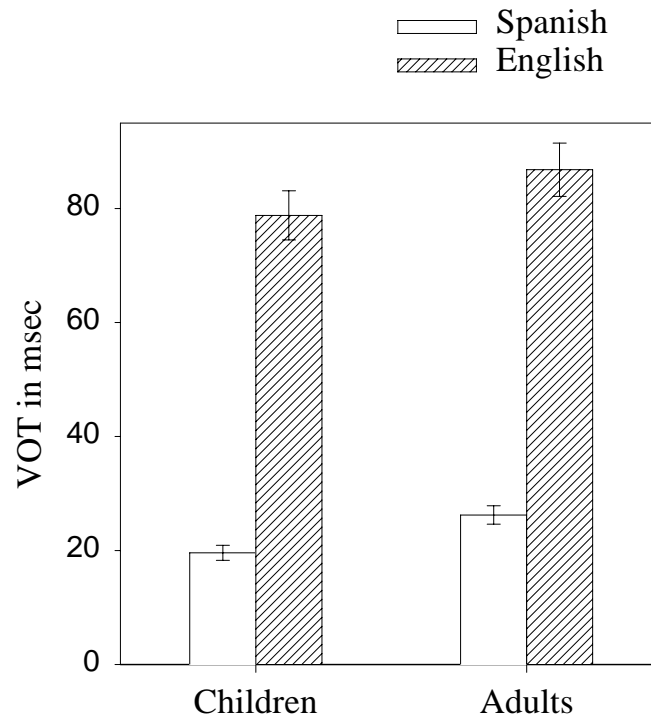


Figure 5. The mean VOT in tokens of /p t k/ produced in the initial position of Spanish and English words by child and adult early bilinguals living in Puerto Rico. From Flege & Eefting (1987).

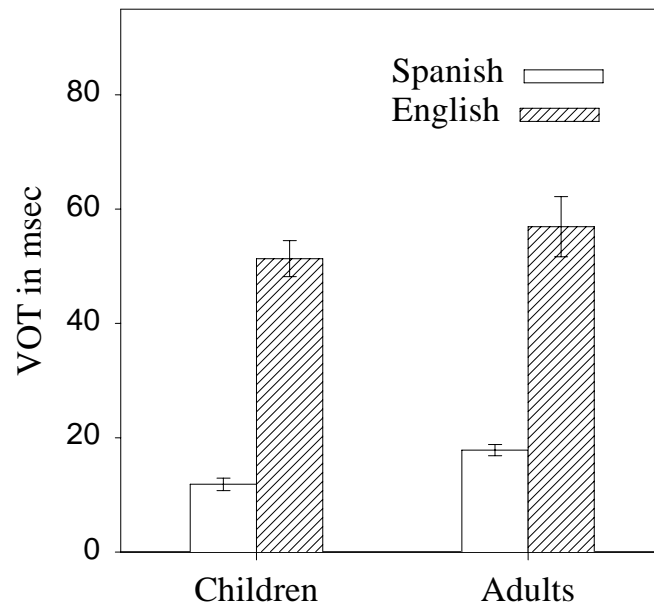


Figure 6. The mean VOT in tokens of /p t k/ produced in the initial position of Spanish words by children and adults who were either monolingual speakers of Spanish or Spanish-English bilinguals. From Flege & Eefting (1986, 1987).

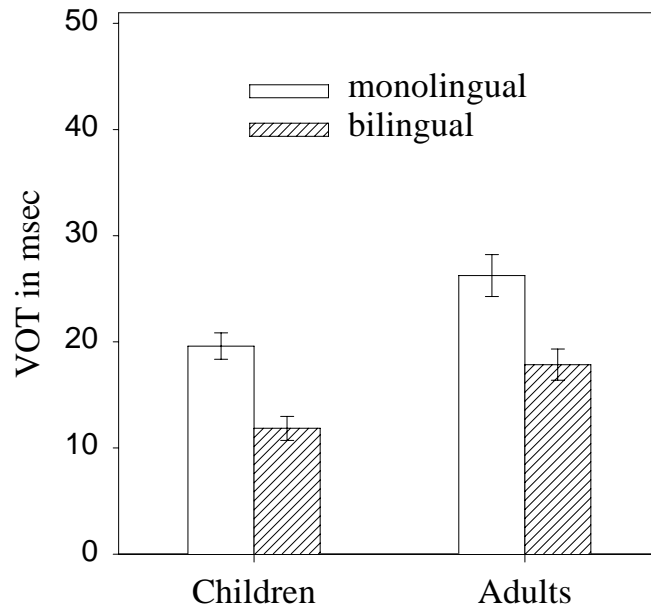


Figure 7. The mean beginning values (marked by x's) and ending values (filled symbols) in productions of English /e^ɪ/ by native English speakers and four groups of Italian-English bilinguals (see text). Positive F1-F0 values indicated an upward movement of the tongue from the beginning to the end of the vowel; positive F2-F1 values indicated a forward movement of the tongue. From Flege et al. (submitted).

