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Release Bursts in English Word-Final Voiceless Stops Produced by Native English and Korean Adults and Children

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Abstract

The aim of this study was to evaluate the acquisition of statistical properties of a second language (L2). Stop consonants are permitted in word-final position in both English and Korean, but they are variably released in English and invariably unreleased in Korean. Native Korean (K) adults and children living in North America and age-matched native English (E) speakers repeated English words ending in released tokens of /t/ and /k/ at two times separated by 1.2 years. The judgments of E-speaking listeners were used to determine if the stimuli were repeated with audible release bursts. Experiments 1 and 2 revealed fewer final releases for K than E adults, and fewer releases for /t/ (but not /k/) for K than E children. Nearly all /t/ and /k/ tokens were heard as intended in experiment 3, which evaluated intelligibility. However, the K adults' /k/ tokens were identified with less certainty than the E adults'. Taken together, the results suggested that noncontrastive (i.e., statistical) properties of an L2 can be learned by children, and to a somewhat lesser extent by adults.

Introduction

Cross-sectional research has shown that adults who were first exposed to a second language (L2) as children ('early' learners) generally outperform adults who were first exposed to their L2 in adulthood ('late' learners) [e.g., Oyama, 1976; Bond and Adamescu, 1979; Cochrane, 1980; Tahta et al., 1981; Flege et al., 1987; Flege and Fletcher, 1992; Yamada, 1995; Baker et al., 2001; Piske et al., 2001, 2002]. One possible explanation for age effects in L2 learning is that the phonetic system of the native

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language (L1) exerts a stronger influence on L2 speech for adults than children because adults have more previous L1 experience than children do [Flege, 1995]. Another possible explanation is that children have not yet passed a critical period for L2 speech learning [see Flege, 1987, and Snow, 1987, for reviews]. One way to distinguish between competing explanations of age-related effects on L2 speech learning is to examine the time course of L2 learning. One might infer from previous cross-sectional research that if children and adults were directly compared, the children would outperform the adults. In other words, early exposure to a foreign language in childhood may be more effective than long exposure in adulthood. However, few direct comparisons of adults and children have appeared in the literature.

The present study examined the acquisition of phonetic details of English by native Korean (K) adults and children who were living in North America. Age-matched native English (E) speakers participated as controls. Most previous studies of L2 speech have focused on the acquisition of phonetic contrasts. For example, a number of studies have shown that native and nonnative speakers of English may differ in their production and/or perception of the voicing contrast in word-final English consonants [e.g., Flege and Port, 1981; Flege and Davidian, 1984; Flege and Hillenbrand, 1986, 1987; Flege et al., 1987; Flege, 1989, 1993; Flege and Wang, 1989; Edge, 1991; Flege et al., 1992; Crowther and Mann, 1992, 1994; Pennington, 1993; Flege et al., 1995; Major and Faudree, 1996; Flege and Liu, 2001]. However, human languages may differ in more than just their system of contrastive phonetic elements. For example, languages may possess either a 'dark' or 'light' /l/, which is contextually conditioned in English in that dark /l/ occurs in syllable codas and light /l/ in syllable onsets. To take another example, mean voice onset time (VOT) values in word-initial tokens of /p t k/ may differ across languages (e.g., English vs. German) in which /p t k/ are realized as aspirated stops. Children learning their L1 acquire such language-specific statistical properties even though they are not necessary to distinguish words in the L1 lexicon.

The phenomenon we are concerned with in this study is the release of final stops, which shows free variation in English. Unlike the 'dark' vs. 'light' /l/, the distribution of release bursts is not apparently conditioned in English. In order to learn to release final stops with the native-like frequency, L2 learners might have to estimate the statistical properties of this distribution. As far as we know, little L2 speech research has focused on the extent to which learners of English approximate the statistical distribution of word-final stop releases seen in the speech of age-matched E speakers [see, however, Zsiga, 2003].

One recent study suggested that L2 learners might be sensitive to the statistical distribution of the input they receive. MacKay et al. [2001] examined the production of word-initial English /b/ tokens by native speakers of Italian. Italian /b/ is always prevoiced whereas English /b/ is usually, but not always, produced with short-lag VOT values. There is no communicative pressure on Italians to produce English /b/ with short-lag VOT values because English /b/ may also be prevoiced in word-initial position. MacKay et al. [2001] found that native Italian speakers who had lived in Canada for many years produced English /b/ with prevoicing less often than is typical for Italian /b/ but more often than was observed for English monolinguals. A significant correlation was observed to exist between the percentage of times the Italian-English bilinguals produced /b/ with prevoicing in English and in Italian words. This suggested that the bilinguals did not establish a new phonetic category for the (mostly) short-lag

/b/ of English, and that the overall distribution of VOT values encountered by the bilinguals in their two languages shaped the distribution of VOT values observed in their production of /b/.

Another example of L2 learners' sensitivity to distributional characteristics of phonetic input comes from a series of training studies conducted by Lively et al. [1993, 1994]. Japanese adults have been found to identify English liquids (/ɹ/ and /l/) more accurately in word-final than word-initial position although the /ɹ/-/l/ contrast is absent in either position in Japanese. Not only was their success dependent on phonetic contexts, but stimulus variability (e.g., familiar vs. unfamiliar voice) also affected their performance. Differing effects of these factors persisted 6 months after training. This finding can be interpreted to mean that the Japanese listeners learned exemplars of English liquids rather than an abstract category encompassing all the variants. Evidence for L2 learners' exemplar learning such as this suggests that the K learners in this study may also be sensitive to differences in distribution of release bursts which, as will be reviewed below, varies as a function of the stop's place of articulation, the preceding vowel's tenseness and so forth.

The aim of this study was to expand our knowledge of the influence of statistical properties of L2 speech input on L2 speech production. It focused on the production of word-final English stops by native speakers of Korean. Korean permits seven consonants (/p t k l m n ŋ/) in final position [Yang, 1978; Choi, 2002]. Korean /p t k/ are not released in prepausal (i.e., word- or coda-final) position [Lee, 1993; Kim, 1998; Sohn, 1999; Lee and Ramsey, 2000; Lee, pers. commun.], as is also the case for other Asian languages [Cantonese: Flege and Wang, 1989; Edge, 1991; Cichoski et al., 1993; Thai: Abramson and Tingsabadh, 1999; Vietnamese: Ingram and Pittam, 1987]. For example, final stops in the Korean words /pap/ 'cooked rice', /pat/ 'to receive' and /pak/ 'gourd' are realized phonetically as unreleased stops.

The range of contrastive phonetic elements in the final position of Korean words is reduced by a coda neutralization rule [Kim and Jongman, 1996; Sohn, 1999; Lee and Ramsey, 2000]. For example, contrasts exist between /t/, /t^h/ and /s/ in word-initial position but they are all phonetically realized as (or neutralized to) [t] in the final position. The tradition in Korean phonology considers coda neutralization to yield unreleased stop in the final position. English, which does not possess such a rule, has a larger inventory of contrastive phonetic elements in word-final position than Korean does. English words may differ according to the voicing and/or place of articulation of word-final stops. Perhaps because of this, English word-final stops are often, but not always released [e.g., Byrd, 1993; Bent and Bradlow, 2003]. The existence of a neutralization rule in Korean leads one to expect that the K adults and children might not release a final stop when speaking English as frequently as the E speakers do.

Previous research has shown that several factors influence the frequency of final release bursts in English stops, including the identity of the preceding vowel [Parker and Walsh, 1981], the gender of the talker [Byrd, 1992, 1993, 1994], place of articulation [Crystal and House, 1988; Byrd, 1993], dialect [Byrd, 1992], speaking style [Picheny et al., 1985, 1986; Bond and Moore, 1994] and the position of the stop within the utterance [Halle et al., 1957]. It is possible then that these factors enable L2 learners to eventually detect variation in the distribution of released and unreleased productions of final stops. The presence of a release burst is not phonemically distinctive in English or in any other languages. For example, whether the final /t/ in 'cat' is or is not released does not alter its meaning. Given the noncontrastive function of release bursts

in both English and Korean stops, an examination of final stop release bursts provided a useful way to assess Koreans' ability to acquire a statistical property of their L2.

Given that final stops are unreleased in a number of languages, one might infer that the absence of release bursts does not impair intelligibility. If that is the case, whether the K learners produce word-final English stops with release bursts or not will have no bearing on their communicative efficiency. However, such a conclusion may be unwarranted. Despite the absence of a contrastive role for release bursts, word-final English stops are somewhat more intelligible if produced with than without a release burst [e.g., Householder, 1956; Malécot, 1958; Wang, 1959]. Recent work suggests that the absence of salient word-final stop consonant releases in nonnative speech might reduce intelligibility [Bent and Bradlow, 2003; Smith et al., 2003]. Listeners' use of release bursts may also depend on prior linguistic experience. Abramson and Tingsabadh [1999] reported that native Thai speakers were better able than naïve American English speakers to identify place of articulation in unreleased word-final Thai stops.

The present study investigated the production of English stops by K adults and children who were living in North America. The K participants examined in this study differed in age (adult vs. child) and length of residence (LOR) in North America (3 vs. 5 years). They were tested at two times (T1, T2) separated by 1.2 years. This design permitted us to test for learning both cross-sectionally (i.e., by comparing the groups differing in LOR) and longitudinally (i.e., by comparing performance at T1 and T2). The aims of the study were to determine if the K children would resemble age-matched E controls to a greater extent than the K adults by producing release bursts more frequently, and if the K children would show greater evidence of learning than the K adults.

Experiment 1

This experiment compared the frequency with which word-final /t/ tokens were produced with a release burst. If one adopted a purely articulatory criterion for whether a stop was or was not released, then all word-final stops would necessarily be defined as 'released' [Henderson and Repp, 1982]. The acoustic effect of articulatory release will be evident in virtually all stops if sufficiently sensitive recording procedures are used [see, e.g., Kim and Jongman, 1996]. The approach used in the present experiment was to use listener judgments to determine if final stops had audible release bursts.

As will be described in greater detail below, the K participants differed in age (adult vs. child) and LOR in an English-speaking community in North America (3 vs. 5 years at the first time of testing, T1). The K adults and children were compared to age-matched E controls at two times of testing separated by 1.2 years. We expected to observe more audible final release bursts for the E than K participants for the reasons outlined earlier. The question of interest was whether the magnitude of native-nonnative differences would vary as a function of age, LOR or time of testing.

Method

Speakers

Three groups of children and three groups of adults (n = 18 each) participated. Both the adults and children differed in terms of LOR in North America: their entire life (for E controls) and either

Table 1. Mean characteristics of the six groups of participants

Group	n	Age	AOA	LOR at T1	LOR at T2
E children	7 m, 11 f	12.7 (2.5) 8–17	–	–	–
LOR5 children	7 m, 11 f	13.7 (2.0) 10–17	8.9 (2.1)	4.9 (0.6)	6.0 (0.6)
LOR3 children	6 m, 12 f	12.3 (2.4) 9–17	9.4 (2.4)	2.9 (0.4)	4.0 (0.4)
E adults	7 m, 11 f	32.3 (4.4) 26–41	–	–	–
LOR5 adults	5 m, 13 f	33.1 (5.3) 27–41	28.3 (5.2)	4.8 (0.6)	5.9 (0.6)
LOR3 adults	8 m, 10 f	30.4 (5.1) 23–40	27.4 (5.0)	3.0 (0.6)	4.1 (0.6)

E = Native English; age = participants' mean chronological age in years (top) and range (bottom); AOA = participants' age of arrival in North America, in years; LOR = participants' length of residence in North America, in years; T1 = Time 1; T2 = Time 2; m = male; f = female. SDs are in parentheses.

3 or 5 years at Time 1 (for the K participants). All 108 participants were living in predominantly English-speaking communities in North America when tested. Thus, unlike the participants examined by Snow and Hoefnagel-Höhle [1977, 1978], the K participants in this study, both adults and children, needed to use their L2 (English) on a regular basis owing to the fact that few people in North America other than Korean immigrants speak Korean.

It was not possible to locate a sufficient number of K participants meeting age and LOR requirements in a single location, so the K participants (and proportional numbers of E controls) were recruited at five sites in North America: the University of Alabama at Birmingham in Birmingham, Ala. (n = 25), Stanford University in Palo Alto, Calif. (n = 22), the University of Illinois in Champaign-Urbana, Ill. (n = 22); the University of Texas at Austin, Tex. (n = 21), and York University in Toronto, Ont. (n = 18). It is possible that the frequency with which stops were released differed between the dialects at these sites and that this difference influenced the likelihood of release bursts in K participants' speech. Unfortunately, the available information on dialect differences in the frequency of releases [Byrd, 1992, 1994] does not permit us to estimate the size of this effect.

Mean characteristics of the six groups of participants are summarized in table 1. One-way ANOVAs revealed that neither the three groups of children nor the three groups of adults differed significantly in age [children: $F(2, 51) = 1.76$, NS; adults: $F(2, 51) = 1.76$, NS]. The K adults had begun to study English in Korea between the ages of 5 and 13 years and had done so for 9 years on average. Seven (of 36) K children had studied English in Korea, beginning at an average age of 9 years for periods lasting from 1 to 3 years. The K children were all attending English-medium schools in the United States or Canada when tested. Ten K adults had received no formal education in North America, but 26 had received an average of 6 years of university education in North America (range = 1–9 years).

Previous research involving young native Spanish adults who had begun learning their L2 Catalan at about school age suggested that an early and extensive exposure to an L2 does not guarantee native-like perception [Pallier et al., 1997]. The K children in the present study were older than the Spanish-Catalan bilinguals by the time they were massively exposed to an L2. If the K children's behavioral plasticity in speech learning was already diminished, they might not be able to learn L2 phonetic properties absent in their L1.

Speech Materials and Elicitation

The participants were tape-recorded individually in a quiet room after completing a language background questionnaire. They produced 24 English consonant-vowel (CV) or CVC words that were picturable as well as familiar. It would have been desirable to control phonetic context,

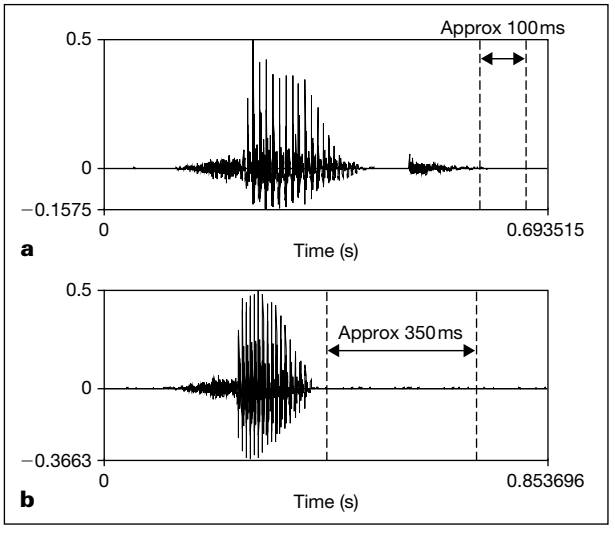

Fig. 1. Sample waveforms of the word *hat* showing cut-off points used in stimuli preparation. **a** Released /t/. **b** Unreleased /t/.

especially the vowels preceding the final stops of interest. However, we considered it even more important to ensure that all words were known by all participants, including the K children.

The test words were elicited three times. During the first elicitation, line drawings of each word were displayed on the screen of a notebook computer. The visual display was accompanied by an auditory model of the word, presented via loudspeakers. The auditory models were spoken by an adult male E speaker; all words ending in a stop consonant were produced with a clearly audible final release burst. The participants were asked to repeat each word after hearing it and seeing its picture on the computer screen. The auditory models were used during the next two elicitations of the test words only when participants could not remember the word associated with a picture. This happened very seldom during the third elicitation.

Stimuli Preparation

The participants' productions of six words ending in /t/ (*eat, feet, eight, date, cat, hat*) were digitized at 22.05 kHz and normalized for peak intensity (50% of the full scale). In most cases, the third token of each word was examined. In all but one instance, these tokens were produced in response to a picture only. Approximately 100 ms of silence was retained before the onset of each test word. Similarly, 100 ms of silence was retained following the cessation of the burst turbulence that was visible in the waveform. The cessation of the burst turbulence was defined as any acoustic energy pertaining to the speech sound. For words without visible evidence of a release burst, 350 ms of silence was retained following the constriction of the final consonant. This was done to ensure that listeners could evaluate even the faintest hint of articulatory release. Figure 1 illustrates the cutoff points for released and unreleased stops.

Listeners and Procedure

The word stimuli were evaluated by 6 E-speaking listeners (3 male, 3 female) with a mean age of 24 years. No listener had training in phonetics or knowledge of Korean. All passed a pure-tone hearing screening at frequencies of 500–8,000 Hz at 20 dB SPL prior to participating. The listeners were tested individually in a sound booth in a session lasting about 70 min. The stimuli were presented via loudspeakers at a self-selected comfortable level.

A practice session with 24 stimuli preceded the experiment. The listeners were told that their task was to determine if they did or did not hear a release burst. The practice stimuli included /t/-final words having release bursts of varying amplitude, words ending in a glottal release, and words ending in a

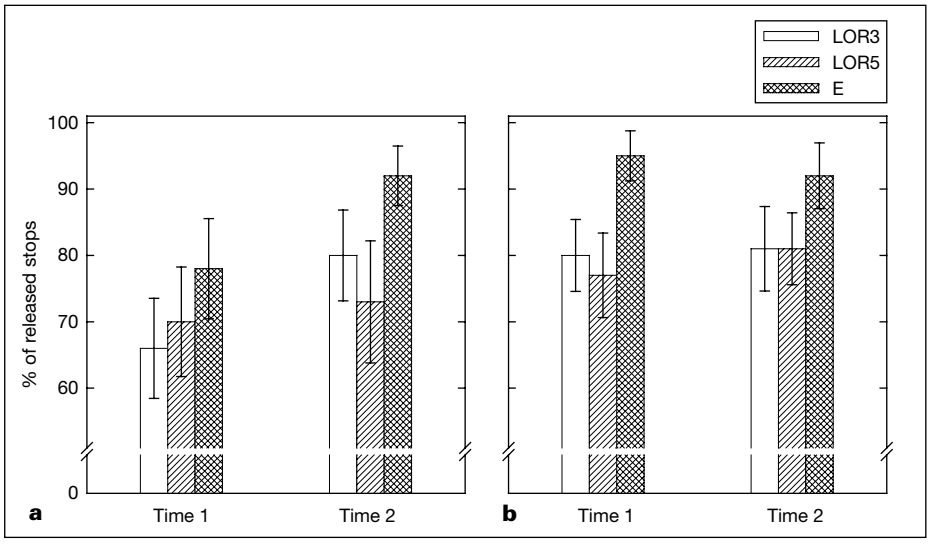

Fig. 2. Mean percentage of the final /t/ tokens judged by 6 listeners to have a release burst in experiment 1. The brackets enclose ± one standard error. **a** Children. **b** Adults.

fricative. The listeners were told to respond 'Yes' if they heard a lingual release, but 'No' otherwise. The interval between each response and the next stimulus was fixed at 1 s. The stimuli could be replayed, but responses could not be changed once given. Practice continued until all tokens were classified correctly. Feedback was not provided during the experiment proper, where the six test words described earlier were presented in counterbalanced order. Each of the six blocks contained 216 tokens (108 speakers × 2 testing times) plus ten extra tokens at the beginning that were not analyzed. Inter-rater agreement was high: Five or more listeners gave the same response (yes or no) to more than 95% of the stimuli.

Analysis

A total of 216 scores were drawn from the 7,776 responses that were obtained (108 speakers × 2 times of testing × 6 words × 6 listeners). The scores, which were each based on 36 judgments (6 /t/-final words × 6 listeners), indicated the percentage of six /t/ tokens produced by each participant that was judged to have a release burst by at least 5 out of 6 listeners. These scores were submitted to an ANOVA in which Age (adult vs. child) and Length of Residence in North America (entire life, 5 years, 3 years) served as between-subjects factors and Time of Testing (T1, T2) served as a within-subjects factor.

Results

Figure 2 shows the percentage of /t/ tokens produced with an audible release (defined as a 'Yes' judgment by at least 5 of 6 listeners) as a function of age, LOR, and time of testing (T1, T2). The E adults released /t/ frequently (>90%) at both times of testing. Frequencies were similar for the E children and adults (means = 92 vs. 91%) at Time 2, but not at Time 1, when the E children released /t/ in less than 80% of instances. As expected, the K participants produced fewer releases than the E participants did. For the

K participants, the mean percentages ranged from 66% (for the K children with a LOR of 3 years at Time 1) to 80% (for the K adults with a LOR of 3 and 5 years at Time 2).

The ANOVA indicated that release bursts occurred more frequently at Time 2 than Time 1 [$F(1, 102) = 4.1$, $p < 0.05$]. Adults released /t/ somewhat more often than children (means = 84 vs. 76%), but the main effect of Age did not reach significance [$F(1, 102) = 2.8$, $p > 0.1$]. The main effect of LOR reached significance [$F(2, 102) = 3.7$, $p < 0.05$] but did not enter into any significant interactions. Post-hoc t-tests revealed that the E participants released stops more often (mean = 89%) than the K participants having a LOR of 5 years (mean = 75%) and those having a LOR of 3 years (mean = 76%), who did not differ from each other.

There was a larger increase in the frequency of release bursts from Time 1 to Time 2 for children (mean = 10%) than adults (mean = 1%). However, the Age × Time interaction narrowly missed significance [$F(1, 102) = 3.6$, $p = 0.06$]. No other interaction reached significance.

Discussion

The E adults produced more bursts than did participants in the remaining five groups, perhaps because they were most sensitive to the need for producing release bursts in a speaking situation that seemed to call for clear (or citation-form) speech typically used in the studio recording where speakers closely monitor their own speech. The E children produced somewhat fewer audible release bursts than the E adults, perhaps because children learning English as an L1 are likely to hear final /t/ tokens reduced, deleted, or rendered as a glottal stop [Bernstein Ratner and Luberoff, 1984; Shockey and Bond, 1980]. The increase in the E children's production of final release bursts from Time 1 to Time 2 may be indicative of children's developing understanding of stylistic differences in the production of English.

The results obtained here suggest that the K participants were learning phonetic details of L2 absent in their L1. It is reported that Korean stops are always unreleased, yet approximately 75% of the K participants' English stops were released in experiment 1. It is important to recall, however, that the K participants heard auditory models of the English words to be produced; all of the auditory models had an audible release burst. Although the words we examined were not produced directly following the presentation of an auditory model, an earlier exposure to the models might have augmented the frequency with which the K participants released English stops. Finally, the lack of a significant Age × LOR interaction suggested that the K children did not show greater evidence of learning statistical properties of the English phonetic system than the adults as they gained experience with English.

Experiment 2

Experiment 1 revealed that the K participants produced word-final English /t/ tokens with an audible release burst less often than the E participants did. The aim of this experiment was to determine if the same would hold true for /k/ tokens produced at the end of isolated words and in words found in utterance-final position. It is known that /k/ is released more often than /t/ in English [Crystal and House, 1988; Byrd,

1993]. If the K participants are sensitive to this distributional difference, their /k/ tokens may be released more often than their /t/ tokens. Stops also tend to be released more often in careful than casual speech [Picheny et al., 1985, 1986; Bond and Moore, 1994; Zsiga, 2003]. If the K participants produced English words less carefully in sentences than in isolation, they might differ even more from the E speakers for /k/ tokens produced at the end of an utterance than at the end of isolated words.

Method

Speech Materials and Elicitation

The only differences between this experiment and experiment 1 pertained to the stop examined (/k/ rather than /t/) and to how half of the test words were elicited. The same 108 speakers as in experiment 1 provided speech materials in this experiment. Three /k/-final words (*duck, neck, sock*) examined here were drawn from the picture naming task described in experiment 1; the remaining three /k/-final words were produced at the end of short sentences: *It's now ten o'clock; He went to work; I read a good book*. The sentences were repeated following aural models produced by a female E speaker [see e.g., Guion et al., 2000; Piske et al., 2001]. The final /k/ tokens in the model sentences all ended with a clearly audible release burst. The three target words (*clock, work, book*) were excised from the sentences using a combination of time-domain waveform and spectrographic cues. Care was taken to ensure that the word onset occurs at the zero-crossing in the waveform so that no click sound would be inserted. Following this, the six /k/-final words produced by each participant were prepared as in experiment 1. All six words sounded natural.

Procedure

The /k/-final words were evaluated auditorily by 6 E speakers (3 male, 3 female) having a mean age of 24 years. The 3 listeners who had not participated previously in experiment 1 passed a pure-tone hearing screening; all 6 listeners heard the stimuli via loudspeakers in a sound booth in a 70-min session. The isolated words and utterance-final words were presented in counterbalanced blocks, each consisting of the randomized presentation of 648 stimuli (6 groups $\times$ 18 participants $\times$ 3 words $\times$ 2 testing times). The listeners responded 'Yes' or 'No' depending on whether they heard a release burst. Once again, interrater agreement was high (at least 5 of the 6 listeners agreed for 97% of the final stops examined). The 7,776 responses that were obtained (1,296 stimuli for each listener) were reduced to 432 (6 groups $\times$ 18 participants $\times$ 2 testing times $\times$ 2 conditions (isolated, utterance-final)) scores, each based on 18 judgments (3 /k/-final words $\times$ 6 listeners). The scores indicated the percentage of the three /k/ tokens produced by each participant in each condition that was judged to have a release burst by at least 5 out of 6 listeners.

The scores were submitted to a four-way ANOVA in which Age (adult, child) and LOR (whole life, 5 years, 3 years) served as between-subjects factors and Time of Testing (T1, T2) and Condition (isolated, utterance-final) served as within-subjects factors. The Condition factor did not reach significance [$F(1, 102) = 2.9$, $p = 0.09$] and did not enter into any significant interactions. The scores from the two conditions were therefore pooled and submitted to a (2) Age $\times$ (3) LOR $\times$ (2) Time of Testing ANOVA.

Results

Figure 3 shows that, unlike the results for /t/ in experiment 1, the E participants' scores were at ceiling (>99%) for /k/. The two groups of K children released final /k/ tokens more than 90% of the time at both times of testing whereas the two groups of K adults did so only about 70% of the time.

The ANOVA carried out to examine the /k/ scores yielded significant main effects of Age [$F(1, 102) = 37.8$, $p < 0.001$] and LOR [$F(2, 102) = 17.3$, $p < 0.001$]. Time of Testing was nonsignificant [$F(1, 102) = 0.1$, $p = 0.70$], however, and did not enter into

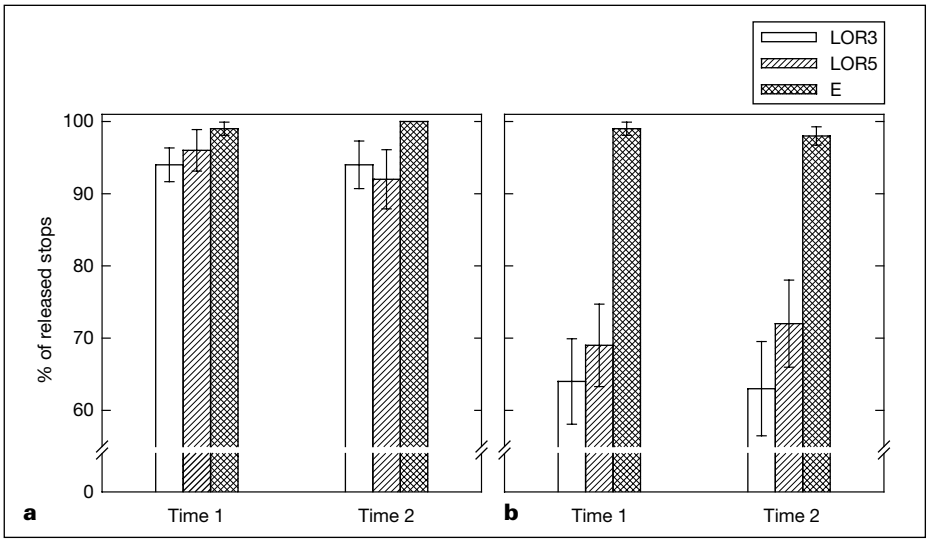

Fig. 3. Mean percentage of the final /k/ tokens judged by 6 listeners to have a release burst in experiment 2. The brackets enclose ± one standard error. Isolated and utterance-final tokens are combined. **a** Children. **b** Adults.

any significant interactions. The ANOVA yielded a significant Age × LOR interaction [$F(1, 102) = 9.1$, $p < 0.001$], which was explored through simple effects tests. The simple effect of Age (adults vs. child) was significant for the K participants with a LOR of 3 years [$F(1, 34) = 24.9$, $p < 0.001$] and those with a LOR of 5 years [$F(1, 34) = 13.3$, $p < 0.001$], but not for the E participants [$F(1, 34) = 0.7$, $p = 0.40$]. That is, the K children produced more release bursts than the LOR-matched K adults whereas the E children did not differ from the E adults.

Differences in the frequency with which the three groups of children released /k/ (E = 99%, LOR 5 = 94%, LOR 3 = 94%) were nonsignificant [$F(2, 51) = 1.8$, $p = 0.20$]. However, the simple effect of LOR was significant for the adult participants [$F(2, 51) = 15.9$, $p < 0.001$]. Post-hoc Tukey tests showed that the E adults produced more release bursts (mean = 99%) than the K adults with a LOR of 5 years (mean = 71%) and the K adults with a LOR of 3 years (mean = 63%), who did not differ significantly from each other.

Discussion

Unlike the results for /t/ in experiment 1, the K children's performance was more English-like than the K adults' for /k/. The K adults produced significantly fewer /k/ release bursts than the E adults, whereas the K children did not differ significantly from the E children.

It is uncertain why different results were obtained for the production of English /t/ and /k/. The pattern of L1-L2 phonetic differences does not predict this outcome. Perhaps the difference was due to the nature of phonetic input that was received. English /k/ is

released more often than English /t/ [Byrd, 1993]. It seems reasonable to think that the K children heard more spoken English than the K adults as a result of shift in language dominance [see Jia and Aaronson, 1999]. Perhaps, too, they heard English /k/ tokens produced with a release burst more often than the K adults. Also, it is likely that there are more divergences from the canonical form of production (e.g., deletion, glottalization) for /t/ than /k/ in child-directed English speech [Shockey and Bond, 1980; Bernstein Ratner and Luberoff, 1984]. Finally, the release bursts in /k/ tokens tend to be longer and to have greater amplitude than /t/ release bursts. Perhaps, as a result, /k/ release bursts are more salient perceptually than /t/ release bursts, and this affected speech acquisition.

None of these explanations are certain, however. It is important to recall that different vowels preceded the /t/ and /k/ tokens examined in this study. Stops are more likely to be released following tense than lax vowels [Parker and Walsh, 1981]. Four out of the six /t/ tokens examined in experiment 1 (*date, eat, eight, feet*) occurred following a tense vowel whereas this held true for just one of the /k/-final words (*work*) examined in experiment 2. Note that we treated the /ɝ/ vowel in *work* as tense here on the basis of the fact that it can occur in stressed open syllables (e.g., *fur, sir*) and that it probably has the longest duration of the five vowel types (/ɛ ɑ ʌ ʊ ɝ/) that preceded /k/.

As a preliminary attempt to evaluate the effect of preceding vowel identity, we examined the scores obtained in experiments 1 and 2 in a series of ANOVAs in which Stop (/t/, /k/) and Preceding Vowel (tense, lax) served as within-subjects factors. Four separate analyses were undertaken. The results for the E adults indicated that they released /k/ significantly more often than /t/ (means = 99 vs. 93%) [$F(1, 17) = 5.85$, $p < 0.05$], but were not affected by preceding vowel context [$F(1, 17) = 0.57$, $p = 0.46$]. Both the K and E children also released /k/ more often than /t/, but only the K children showed an effect of preceding vowel context [$F(1, 35) = 8.0$, $p < 0.001$], and then only for /t/ (following tense vowels: 76%, following lax vowels: 64%).

The ANOVA examining the K adults' scores, on the other hand, yielded an effect of Preceding Vowel [$F(1, 35) = 47.9$, $p < 0.001$] and a Stop × Vowel interaction [$F(1, 35) = 17.3$, $p < 0.001$]. There was little overall difference in the K adults' scores for /t/ and /k/ (means = 78 and 79%, respectively). However, the K adults released more stops following tense than lax vowels (means = 90 vs. 67%). The vowel context effect was particularly striking for /k/: 97% of tokens were released following tense vowels as compared to just 61% following lax vowels. Additional research will be needed to confirm or disconfirm these preliminary findings, which indicate a different pattern of interaction between vowel quality and stop place for different groups of participants [Pikser and Strange, 2002].

Experiment 3

Previous work suggests that stops produced without a release burst are less intelligible than stops having a release burst [e.g., Malécot, 1958; Wang, 1959; Lisker, 1999]. Experiments 1 and 2 showed that K learners of English may release English /t/ and /k/ less often than E speakers. The purpose of this experiment was to evaluate the effect of native-nonnative differences in production on listeners' judgments. We did so by having E listeners classify word-final stops drawn from experiments 1 and 2 as either 't' or 'k'. One possible outcome of this experiment is that the lower frequency of audible release bursts in stops produced by K than E speakers would result in native-nonnative differences

in intelligibility. Another possibility we considered was that, even if the K participants' stops were identified as intended, small divergences from English phonetic norms might reduce E listeners' certainty as to the identity of the K participants' stops.

Method

Procedure

The stimuli examined here were six words drawn from experiments 1 and 2. Three ended in /t/ (*cat, date, eight*) and three in /k/ (*clock, duck, neck*). The consonants initiating five of the six words were deleted to minimize potential lexical biases. Inevitably, however, some words remained real English words and the difference in lexical status among the test words was not completely eliminated. The onset of the vowel in all six words were then ramped on over the first 30 ms. Finally, the /Vt/ and /Vk/ syllables were normalized for peak intensity (50% of the full scale). The VC syllables yielded by these procedures were presented to 6 E-speaking listeners (3 male, 3 female) having a mean age of 24 years. All of the listeners had participated previously in experiment 1 and/or 2.

The listeners were tested one at a time in a sound booth in a single session lasting about 70 min. The stimuli were presented via loudspeakers at a self-selected comfortable level. Syllables derived from words spoken by adults and children were presented in separate, counterbalanced blocks. Within these two blocks, words spoken by groups differing in LOR in North America (entire life, 5 years, 3 years) were presented in counterbalanced order. In each of the six blocks, 216 stimuli (6 words $\times$ 18 participants $\times$ 2 testing times) were preceded by 10 extra practice tokens that were not analyzed.

The listeners were told to use one of the following labels to classify each syllable-final consonant: 'DEF t' (i.e., definitely a /t/), 'PROB t' (probably a /t/), 'POSS t' (possibly a /t/), '?' (uncertain), 'POSS k', 'PROB k', 'DEF k'. The listeners were told to use one of the two buttons marked 'definitely' only if they were '100% sure' of their response category. They were asked to use the buttons marked 'probably' and 'possibly' to indicate lesser degrees of certainty. The listeners were told to use the '?' label if they had 'no idea at all' as to category identity (i.e., /t/ or /k/).

The 7,776 responses obtained using this procedure (1,296 stimuli $\times$ 6 listeners) were reduced to 432 (6 groups $\times$ 18 participants $\times$ 2 testing times $\times$ 2 stops (/t/, /k/)) scores, each based on 18 judgments (3 words each ending with /t/ or /k/ $\times$ 6 listeners). The scores formed a scale ranging from 0 to 3, with 3 indicating the highest degree of certainty in stop identity. These 'phonetic quality' scores were examined in a preliminary four-way ANOVA in which Age (adult, child) and LOR in North America (entire life, 5 years, 3 years) served as between-subjects factors, and Time of Testing (T1, T2) and Consonant (/t/, /k/) served as within-subjects factors. The Time factor was nonsignificant and did not enter into significant interactions. Therefore, the scores obtained at Times 1 and 2 were pooled and submitted to a (2) Age $\times$ (3) LOR $\times$ (2) Consonant ANOVA.

Results

Figure 4 shows the mean phonetic quality scores obtained for /t/ and /k/. With the exception of just one token, all stops were heard as intended (i.e., as /t/ or /k/). However, listeners' certainty as to stop identity varied. The /k/ but not /t/ tokens produced by the two groups of K adults received lower scores than stops produced by the remaining four groups of participants. All three main effects reached significance [Age $F(1, 102) = 10.8$, $p < 0.01$; LOR $F(2, 102) = 11.3$, $p < 0.01$; Consonant $F(1, 102) = 12.9$, $p < 0.01$], as did all interactions [Age $\times$ LOR $F(2, 102) = 5.1$, $p < 0.01$; Age $\times$ Consonant $F(1, 102) = 51.1$, $p < 0.01$; LOR $\times$ Consonant $F(2, 102) = 7.7$, $p < 0.01$; Age $\times$ LOR $\times$ Consonant $F(2, 102) = 10.1$, $p < 0.01$].

The three-way interaction was explored through simple effect tests. There were no significant between-group differences for /t/. The simple effect of LOR was significant for the adults' production of /k/ [$F(2, 51) = 13.9$, $p < 0.001$] but not the children's [$F(2, 51) = 0.4$, $p = 0.67$]. Post-hoc Tukey tests revealed that the listeners

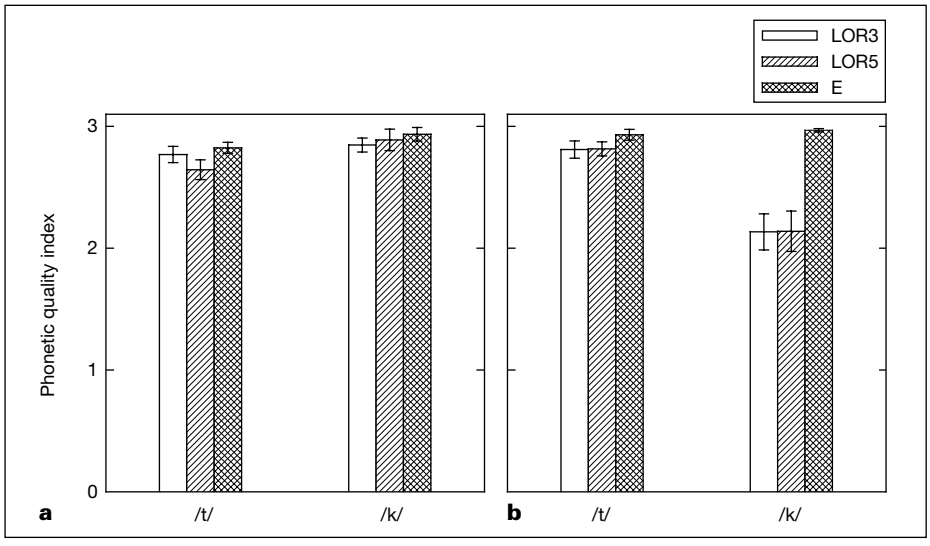

Fig. 4. Mean phonetic quality scores for the final /t/ and /k/ by 6 listeners in experiment 3. 0 means 'no idea' and 3 means 'definitely /t/ or /k/'. Scores are averaged over two times of testing (T1 and T2). The brackets enclose ± one standard error. **a** Children. **b** Adults.

were more confident of the identity of /k/ tokens produced by the E adults than by the K adults having a LOR of 5 years and the K adults having a LOR of 3 years, who did not differ from each other. The simple effect of Age was significant for the /k/ tokens produced by the K participants with a LOR of 5 years [$F(1, 34) = 15.8$, $p < 0.001$] and a LOR of 3 years [$F(1, 34) = 20.2$, $p < 0.001$], but not for the E participants [$F(1, 34) = 0.3$, $p = 0.58$]. This meant that the listeners were more confident of the identity of /k/ tokens produced by the K children with LORs of 3 and 5 years than by the K adults who had resided in North America for the same length of time.

Discussion

The E listeners were less certain of the identity of /k/ tokens produced by the K adults than the E adults. Although the K adults' /k/ tokens were identified as intended, they were apparently not of high phonetic quality. The /t/ tokens produced by all six groups received high scores, ranging from 2.64 (for the K children with a LOR of 5 years) to 2.93 (for the E adults). This suggests that the E listeners tended to be confident of the identity of /t/ tokens, even in the absence of a release burst.

The results obtained for the K adults suggested that, in some instances at least, the E listeners' were more confident of the phonetic identity of stops produced with than without an audible release burst. We carried out an exploratory correlation analysis to better understand the relationship between the presence/absence of release bursts and perceived phonetic quality. Figure 5 plots values for each of the 108 participants' production of /t/ and /k/ (averaged across six tokens each). The x axis shows the percentage of stops judged to have an audible release burst in experiment 1 or 2. The

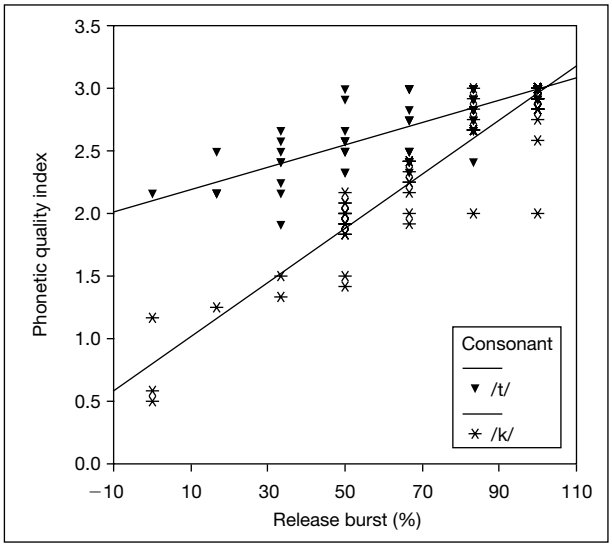

Fig. 5. Correlation between the frequency of release burst and mean phonetic quality scores for the final /t/s and /k/s (six tokens each) by 108 participants in experiment 3. Percentages of release burst occurrence are expressed as integer multiples of 100/6. Scores are averaged over two times of testing (T1 and T2).

y axis shows the average phonetic quality scores obtained for the same six stops. The participants who frequently released final stops tended to elicit more confident judgments (what we call 'phonetic quality') than the participants who seldom released final stops. This held true both for the /t/ tokens [$r(106) = 0.85$, $p < 0.01$] and the /k/ tokens [$r(106) = 0.95$, $p < 0.01$].

General Discussion

This study evaluated the learning of noncontrastive phonetic properties of an L2 by examining how often K learners of English produced English word-final stops with audible release bursts. Final stops are not released in Korean [Lee, 1993; Kim, 1998; Sohn, 1999; Lee and Ramsey, 2000; Lee, pers. commun.]. Despite this, we found that the K participants who had lived in North America for periods ranging from 3 years (the LOR 3 participants at Time 1) to 6 years (the LOR 5 participants at Time 2) frequently (>60%) released final stops in English. Although the K participants seem to have modified their production of word-final stops as the result of exposure to English, the study nevertheless provided evidence that the K participants' phonetic realization of English stops was not always equivalent to the E speakers'.

The E participants generally released word-final English stops more often than the K participants, especially the K adults. The K children showed more English-like performance than the K adults for /k/ but not /t/. We offered several potential explanations for the /t/-/k/ difference, which could not be explained in terms of L1-L2 differences. The explanation that is most likely to be true, in our opinion, is that the K children had heard more released /k/ tokens but not /t/ tokens than the K adults did. Note that this explanation assumes that L2 learners, both children and to some extent adults, are sensitive to the statistical distribution of phonetic properties in the L2 speech input they receive.

The K participants differed according to their LOR in North America at Time 1 (3 vs. 5 years). An extra 2 years of residence in North America did not result in significantly more English-like performance; and performance was no more English-like at Time 2 than Time 1 (i.e., after an additional 1.2 years of residence in North America). Thus, our data failed to provide cross-sectional (LOR 3 vs. LOR 5) or longitudinal (Time 1 vs. Time 2) evidence of learning. It is important to note, however, that all four K groups showed a relatively high frequency of release bursts at Time 1 as well as Time 2.

If beginners are found to release English stops infrequently, it would confirm that the Korean participants in this study had already modified their production of word-final stops considerably. If Koreans who are even more experienced than those tested here were to be found to resemble E speakers in a wide range of contexts, lexical items, and speaking styles, it would demonstrate that the acquisition of noncontrastive phonetic aspects of an L2 is indeed possible.

A number of other questions with respect to statistical learning are suggested by the results of this study. For example, is it more difficult for native speakers of Korean (a language with unreleased final /p t k/) to learn the final stops of English, which are variably released, than to learn the final stops of French, which are almost always released? Conversely, would French speakers have more difficulty in learning to reduce the frequency of releases in word-final English stops than in learning to *never* release final stops in Korean?

A more general question is whether it is harder to acquire contrastive than noncontrastive phonetic characteristics of an L2. To address this question, it would be valuable to examine Koreans' production of word-final English /p t k/ tokens using a speech sample in which both preceding vowel context and lexical familiarity were controlled. We suspect that Koreans will release English stops more frequently in familiar than unfamiliar (or unknown) English words, and in stops following tense than lax vowels. Another question of interest is whether the phonetic properties of words being repeated will influence production by K participants to a greater extent than E participants.

In summary, the present study suggested that K children, and to some extent K adults, acquired noncontrastive (i.e., variable) phonetic aspects of English that do not exist in Korean. The initial advantage of adult L2 learners over child L2 learners in previous research [Snow and Hoefnagel-Höhle, 1977, 1978] was not replicated. To better understand what factors might influence the extent of L2 speech learning, suggestions were offered for future research.

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