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The production of "new" and "similar" phones in a foreign language: evidence for the effect of equivalence classification

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Acoustic measurements were made of the voice onset time (VOT) and vowel formants (F_1–F_3) in French and English words spoken by native French subjects who were highly experienced in English, and by three groups of native English subjects differing according to French-language experience. The speech of monolingual subjects was also examined to estimate the phonetic norms of French and English. It was hypothesized that equivalence classification limits the extent to which L2 learners approximate L2 phonetic norms for "similar" L2 phones judged to be realizations of a category in L1 (e.g. /u/ and /t/ of French and English), but not a "new" L2 phone which has no counterpart in L1 (French /y/ for the native English subjects). Native English subjects who were experienced in French did not differ from French monolinguals in producing French /y/. However, the subjects in all four groups produced /u/ in their L2 with F_2 values which differed significantly from those of native speakers; and they all produced /t/ in their L2 with mean VOT values that either closely resembled the L1 phonetic norm, or were intermediate to the phonetic norm for VOT in L1 and L2. L2 learning was also shown to influence production of /t/ in L1. The native French subjects who spoke English produced French /t/ with longer (i.e., English-like) VOT values than French monolinguals; and the most experienced native English speakers of French produced English /t/ with shorter (French-like) VOT values than English monolinguals. Taken together, these results suggest that the phonetic space of adults is restructured during L2 learning, and support the hypothesis that equivalence classification prevents experienced L2 learners from producing similar L2 phones, but not new L2 phones, authentically.

1. Introduction

The "crystallization" which prevents certain songbirds from learning new songs after specific developmental milestones have been passed (Marler & Mundinger, 1971) provides an analogy for possible maturational effects on human vocal learning. Foreign accent in adult speech is often cited as evidence that humans show a "critical period" for certain aspects of speech learning (Penfield & Roberts, 1966; Lenneberg, 1976; Scovel,

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1969, 1981; but cf. Oyama, 1982; Flege, 1986*b*). Differences between native and non-native speakers in segmental articulation undoubtedly contribute to foreign accent (Flege, 1984). One might therefore hypothesize that the ability to learn new patterns of segmental articulation in speech diminishes after a critical period has been passed in human development.

The issue addressed here is whether such a diminution of ability in human vocal learning ability, should it be shown to exist, applies equally to all of the phones in an L2. More specifically, it examines the extent to which L2 learners approximate the phonetic norms of an L2 for "new" and "similar" phones. Languages differ both in terms of the number of contrastive sound units they possess, and according to how those units are realized articulatorily. From the standpoint of L1, the phones in an L2 may be taxonomized acoustically as "identical", "similar", or "new" (Flege, 1968*a*).

"New" L2 phones have no counterpart in the L1 and so, by definition, differ acoustically from phones found in L1. For example, realizations of French /y/ are "new" phones for native speakers of English. Although [y] phones may sometimes occur on the phonetic surface of American English as an allophone of /u/ (as in [mjyzIk] for "music"), English has no /y/ category. Native English speakers may at first identify French /y/ as /u/, despite the fact that it differs considerably in terms of second formant (F_2) frequency from English /u/ (and to an even greater extent from French /u/; Debrock & Forrez 1976; Flege & Hillenbrand, 1984). However, an important assumption made here is that they will eventually come to recognize that [y] is not the realization of an English category (or French/u/).

"Similar" L2 phones, on the other hand, differ systematically from an easily identifiable counterpart in L1. For example, /t/ is found in both French and English, but it is implemented as a short-lag stop with dental place of articulation in French, and as a long-lag stop with alveolar place of articulation in English. The /u/ of French and English must also be classified as similar, for /u/ is realized with somewhat higher and more variable second formant (F_2) frequencies in English than French (Delattre, 1953; Stevens & House, 1963; Adamczewski & Keen, 1973; Shockey, 1974; Valdman, 1976; Debrock & Forrez, 1976; Labov, 1981).

It is commonly accepted that L2 learners "identify" L2 phones in terms of native language (L1) categories and, as a result, use articulatory patterns established during L1 acquisition to realize those L2 phones (Weinreich, 1968; Catford, 1965; Valdman, 1976). The traditional view is that L2 learners' difficulty in pronouncing phones in an L2 is largely confined to those phones which did not occur systematically on the phonetic surface of L1 (van Heuven, 1986; Brière, 1966). This suggests two possibilities. L2 learners either make the small articulatory modifications needed to realize similar L2 phones differently than their counterparts in L1. Or, if they do not, the production of similar L2 phones according to L1 phonetic norms goes unnoticed by listeners.

James (1985) noted that nearly all L2 speech errors involve phonemes which either do not occur, or are realized differently, in L2 and L1. This suggests that L2 learners may have difficulty establishing the articulatory patterns needed to produce both new and similar L2 phones authentically; or, contrary to the assumption stated above, they may continue to identify both new and similar L2 phones in terms of an L1 category.

Several hypotheses can be offered for why L2 learners do not produce L2 phones authentically. First, they might not perceive L2 phones accurately. Trubetzkoy (1939/1969) was apparently the first to hypothesize formally that having learned the phonology of L1 causes L2 learners to "filter out" perceptually acoustic differences that are not

phonemically relevant in L1. This might explain why, for example, Japanese speakers confuse English /r/ and /l/. Phonological filtering might also prevent L2 learners from detecting auditorily the acoustic differences that distinguish similar phones in L1 and L2. This last hypothesis is unlikely to be correct, however, for recent research has shown that adults are sensitive to the small acoustic differences distinguishing the similar phones in two languages (Flege, 1984; Flege & Hammond, 1982).

Difficulty in producing L2 phones authentically might be motoric in nature. Adults might be generally less able than young children to develop new articulatory patterns or to translate the sensory information associated with new L2 phones into stable motor control patterns. Adults might also be less able than children to modify previously established articulatory patterns (Kalikow & Swets, 1972). For example, native speakers of French might realize the /s/ in English words with a dental rather than alveolar place of articulation (Valdman, 1976) because they are unable to modify articulatory patterns, not because they fail to detect the acoustic differences between English and French /s/ that might arise from small differences in phonetic realization. It is also possible that social and/or psychological factors prevent adults from maximizing their capabilities for speech learning.

The goal of this research, however, is to test another broad hypothesis: namely, that as the result of the development of the L1 phonetic system, the effect of a mechanism called equivalence classification prevents adults from producing L2 phones authentically by rendering them unable to make effective use of sensory input in speech learning (Flege, 1981, 1986*a*; Flege & Hillenbrand, 1984).

Equivalence classification is a basic cognitive mechanism which permits humans to perceive constant categories in the face of the inherent sensory variability found in the many physical exemplars which may instantiate a category. It is known that children and adults use somewhat different strategies to categorize word, picture, or object arrays (e.g. Bruner, Oliver & Greenfield, 1966; Nelson, 1974; Anglin, 1977). A classic view is that children become increasingly less reliant on sensory information as they develop cognitively. Bruner (1964) suggested three major stages: an enactive stage, with its reliance on motoric codes; an iconic stage, where reliance shifts to sensory or perceptual codes; and finally a symbolic stage. Bruner has suggested that, as children mature, they rely less on finding the common features which identify specific exemplars as belonging to a category, and more on higher order, superordinate, categories in a symbolic hierarchy.

Infants possess the ability to recognize the similarity of acoustically different realizations of a single phonetic catogory (Kuhl, 1980; Hillenbrand, 1983, 1984). If development of the phonetic categories used for the identification and implementation of phonemes follows the general course of "concept" formation, we would expect to see an evolution in speech perception as children develop. The existence of differences in speech perception between individuals of different native language backgrounds suggest that children gain detailed information concerning the sensory attributes of the phonetic categories found in the language(s) spoken around them (Abramson & Lisker, 1970; Flege & Eefting, 1986*b*). It also suggests that they gradually "attune" their perceptual processing of speech to optimally conform to phones found in the ambient language(s) (Aslin & Pisoni, 1980). Speech production research (e.g. Flege, McCutcheon & Smith, 1986) suggests that children also gradually develop the ability to realize phones according to the phonetic norms of their L1 through language-specific realization rules.

Equivalence classification is undoubtedly important for L1 learning because it permits children to identify phones produced by different talkers, or in different phonetic

contexts, as belonging to the same category. Flege (1981) hypothesized that although equivalence classification may enable young children to learn the authentic production of L1 phones, it may lead to foreign accent in older children and adults by preventing them from making effective use of auditorily accessible acoustic differences between phones in L1 and L2.

Scovel's (1981) finding that the ability to detect foreign accent increases with age suggests that phonetic categories become better defined, perhaps because listeners encounter an increasingly wide variety of realizations of each category in the L1. Werker & Logan (1985) found that listeners may optionally process speech at a phonetic or auditory level. If humans rely increasingly less on sensory information in making categorical decisions as they mature, and if, at the same time, they become capable of identifying an increasingly wide range of phones as belonging to a phonetic category, it may become increasingly difficult for L2 learners to note the phonetic (but not auditory) difference between "similar" phones in L1 and L2.

Unlike young children just beginning to acquire their L1, older children and adults learning an L2 have a well established inventory of phonetic categories. We must presume that L2 learners, like infants, seek constancy in the sensory information they process. If so, they are likely to judge L2 phones (even those which differ auditorily from phones in L1) as being the realization of an L1 category, for they have become accustomed to the wide range of variants used to realize a single category.

One hypothesis to be tested here is that equivalence classification prevents adult L2 learners from establishing a phonetic category for similar but not new L2 phones. It is not certain at present whether L2 learners identify every phone in L2 as belonging to a previously established L1 category. Some phones in L2 seem to be so dissimilar acoustically and articulatorily from phones in L1 (e.g. the clicks in SeSotho, from the standpoint of English) that equivalence classification is unlikely to occur. However, it is more difficult to make *a priori* predictions regarding many other phones in an L2. As mentioned earlier, an assumption made here is that native English speakers will eventually recognize that /y/ is a separate category. Another important assumption is that L2 learners will be unable to produce authentically L2 phones that differ acoustically from phones in L1 unless they establish a phonetic category for the L2 phones.

If these assumptions are correct, and if adults have not passed a "critical period" for speech learning, highly experienced native English speakers of French should produce the new French vowel /y/ authentically, but not the similar French vowel /u/. To test this, the present study directly compared the authenticity with which native English subjects produced the new French vowel /y/ and the similar French vowel /u/. The phonetic norms of French for /u/ and /y/ were estimated by examining the speech of French monolinguals; the phonetic norm of English for /u/ was based on the speech of English monolinguals. If L2 learners eventually produce new L2 phones more authentically than similar L2 phones, experienced native English subjects should differ significantly from the French monolinguals in producing /u/ but not /y/.

A second, related, hypothesis is that L2 learners will approximate but not achieve the phonetic norms of L2 for similar L2 phones as they gain experience in L2. This hypothesis rests on two assumptions: namely, that L2 learners are able to detect auditorily the acoustic differences distinguishing similar L1 and L2 phones; and the phonetic representations which guide segmental articulation continue to be modifiable throughout life as the result of phonetic input. Previous research has shown that experienced L2 learners may produce similar L2 phones differently than their L1 counterparts, albeit

not authentically (e.g. Flege, 1980; Flege & Port, 1981; Flege & Hillenbrand, 1984). The hypothesis will be tested here by examining the production of similar L2 phones by native English and French subjects who are highly experienced in their L2. If the hypothesis is correct, then L2 speech should diverge from the phonetic norm of the L2 (as defined by the speech of the monolingual subjects), but less than that of relatively inexperienced L2 learners.

Flege (Flege, 1981; Flege & Hillenbrand, 1984) hypothesized that an upper limit exists on the extent to which L2 learners approximate L2 phonetic norms for similar phones because L2 learners "merge" the phonetic properties of similar L1 and L2 phones within a single category. For example, the phonetic representation of native French speakers of English for /t/ may change to reflect their exposure to [t] phones in French and [t^h] phones in English if both kinds of stops are identified as realizations of the category /t/. L2 learners have, in fact, been observed to produce the /t/ in L2 with "compromise" VOT values that were longer than the values typical for L1, but shorter than the values typical for L2 (Caramazza, Yeni-Komshian & Zurif, 1973; Williams, 1980).

The merger hypothesis was tested here by determining whether L2 learning affects the production of stops in L1. If the merger hypothesis is correct, we would expect to see an L2 effect on L1 production in addition to the expected L1 effect on L2 production (i.e. "interference"). This is because the single phonetic category representation used to implement /t/ in L1 and L2 should have been influenced by phones in both L1 and L2 as the result of equivalence classification.

2. Methods

2.1. *Subjects*

Forty-two women, all with normal hearing according to self-report, participated as subjects. They were divided into six groups, labelled A–F, which differed primarily according to previous linguistic experience.

Groups of French and English monolinguals were formed to provide an estimate of the phonetic "norms" of those two languages. The monolingual English subjects (Group A) had a mean age of 26 years. They had been born of English-speaking parents, raised in or near Chicago, and were all Speech-Language Pathology students at Northwestern University. Several had studied French for 1–2 years in high school, but none of them could carry on even a simple conversation in French or any other L2. The monolingual French subjects (Group F) had a mean age of 37 years. They were nursing aids in a large hospital in Paris who had been born in or near Paris. These subjects were chosen because they had relatively little formal education in English, had received only minimal exposure to English, and had never lived or vacationed extensively in an English-speaking country according to self-report. The author verified they did not speak English by trying, unsuccessfully, to converse with them in English.

Three groups of native speakers of American English who had learned French as an L2 in late adolescence or early adulthood were formed. These subject groups differed primarily according to French-language experience, but also according to amount of formal education in L2, length of residence in an L2-speaking environment, and the frequency with which they spoke French in the period preceding the study. Most of them had studied French in high school or college, but their first massive exposure to the French spoken by native speakers occurred in early adulthood, in France.

The least experienced native English subjects (Group B) had a mean age of 22 years. These subjects were students at Northwestern University who had spent the previous academic year (9 months) in Paris. They had had little opportunity to speak French in the 3–6 months preceding the study. The subjects in Group C (mean age, 32 years) had more French-language experience. Each of them held an advanced degree(s) in French, and was teaching French at Northwestern University or Indiana University at the time of the study. The subjects in Group C had spent several periods of time in France, which together totaled an average of 1.3 years. Although they spoke French frequently in the context of their professional activities, English was their principal language at the time of the study.

The subjects in the most experienced native English group (Group D) had a mean age of 35 years. They had much less formal education in French than the Group C subjects, but much more exposure to the French spoken by native speakers than the subjects in Groups B or C. The subjects in Group D were married to native speakers of French and had been living in Paris for an average of 11.7 years at the time of the study. Most of them had children who spoke French as their principal language and attended French-speaking schools. These subjects indicated that, although they spoke English in the home to encourage bilingualism in their children, French was their principal language at the time of the study.

Finally, a group of native French subjects (Group E) was formed to match the native English subjects in Group D. These subjects, whose mean age was 38 years, had been living in Chicago for an average of 12.2 years at the time of the study. Four were originally from Paris; one was from Annecy; and two were from Belgium. The subjects in Group D had at least seven years of formal education in English. Four were married to native English speakers. Like the native English subjects in Group D, the native French subjects to Group E found opportunities to speak their L1, but L2 (English) was clearly their principal language.

2.2. *Procedures*

The four sets of phrases in Table I were used to elicit English and/or French speech production, but only the sets beginning with *two*, *tous*, and *tu* were examined. These words were chosen to ensure lexical familiarity. *Tu* is the second person singular pronoun meaning "you"; *tous* is an adjective meaning "all". Both the French and English phrases were used to elicit production by the subjects in Groups B–E. The order of the words (*tous* vs. *tu*, *two* vs. *TV*) and language (for the subjects who produced both French and English materials) was counterbalanced across subjects within each group.

The speech material was recorded on a professional-quality portable cassette tape recorder (Sony model TCD5M) using an electret condensor microphone (Nakamichi model CM-300) positioned about six inches from the talker's mouth. The subjects in Groups A, B, C, E and F were recorded in a sound treated room. The subjects in Group D were recorded in the most quiet room available in their Paris home.

The subjects in all six groups produced the test phrases in two speaking conditions to ensure a representative sampling of their speech production. In the Phrase condition, they simply read the seven phrases in each set from a list. In the Sentence condition, they produced complete, original sentences based on the phrases just read in isolation. Production was cued by the same written lists in both conditions. The subjects were

TABLE I. The phrases used to elicit the production of /tu/ and /ty/ in French, and /tu/ in English

English		French	
/tu/	/ti/	/tu/	/ty/
1. two little boys	TV programs	tous les prêtres	tu les montres
2. two little girls	TV schedules	tous les évêques	tu les opposes
3. two little cats	TV ratings	tous les soldats	tu les observes
4. two little dogs	TV violence	tous les marins	tu les renvoies
5. two little birds	TV reception	tous les médecins	tu les obtiens
6. two little mice	TV antennas	tous les dentistes	tu les informes
7. two little men	TV commercials	tous les gendarmes	tu les regardes

required to produce a number and to pause before producing the phrases in both conditions[1].

2.3. *Analyses*

The recorded speech material was low-pass filtered at 4 kHz before being digitized with 11-bit amplitude resolution at a 10 kHz sampling rate. Two acoustic measurements were made from the digitized waveforms. Voice onset time (VOT) was measured to the nearest 0.1 ms from the display of a high resolution graphics terminal. The left cursor was set at the sharp increase in waveform energy which signaled the release of /t/. The right cursor was set at the first upward-going zero crossing which signaled voicing onset.

The frequencies of vowel formants were estimated using linear predictive coding (LPC) analysis. The centre frequencies of the first three formants (F_1–F_3) were estimated by positioning the left margin of a 25.6-ms full Hamming window at the onset of periodicity. The frequency values were derived from the smoothed spectra by a peak-picking algorithm. In those instances where a 12-coefficient model did not provide credible estimates, a 14- or 16-coefficient model was used.

The mean values of the VOT interval in /t/, and the F_1–F_3 values in /u/ and /y/, were based on the five observations obtained in two speaking conditions for each subject in the words initiating phrases 2–6. If an utterance-initial word proved to be unanalyzable (because of intermittent noise, for example), it was replaced by the word initiating phrase 1 or 7. In no instance was a mean value based on fewer than three observations per subject.

Preliminary analyses revealed that the effect of Speaking Condition was non-significant, so a mean of the mean values obtained for the two speaking conditions was used in subsequent analyses. (See Flege & Hillenbrand, 1984, for additional discussion regarding the role of "attention to speech" in the production of foreign languages.) One-way randomized block ANOVAs examined production of English *two* by the subjects who produced the English material (Groups A–E). A series of mixed-design Group × Language ANOVAs examined production of French *tous* and English *two* by the

[1]The subjects in Groups A–D also produced phrases in a "Story" condition designed to yield a spontaneous, yet phonetically controlled, speech sample. The data for this condition were not reported here because comparable data could not be obtained for the subjects in Groups E and F, and because the results of perceptual tests and a preliminary acoustic analysis (Flege, 1984; Flege & Hillenbrand, 1984) indicated that the speech produced in the Story condition did not differ significantly from speech produced in the Isolated Phrase and Sentence conditions.

subjects who produced both the English and French material (Groups B–E). Finally, mixed-design Group × Word ANOVAs examined production of *tous* and *tu* by the subjects who produced the French material (Groups B–F). Significant two-way interactions were explored by tests of the simple main effects of Group and Language, or Group and Word (Kirk, 1968). When the effect of Group was significant, post-hoc comparisons were also performed using the Newman–Keuls procedure with an α level of 0.05.

3. Results

3.1. *Stop consonant production*

The mean VOT of /t/ in the French word *tous* (/tu/) and the English word *two* (/tu/) is represented in Fig. 1 by bars for the subjects in Groups B–E, and by horizontal lines for the monolingual native speakers of English and French (Groups A and F, respectively). The native English speakers who were least experienced in French (Group B) produced /t/ with a mean VOT that was hardly shorter in French (72 ms) than English (77 ms). The VOT they produced in French /t/ differed very little from the mean VOT observed in the /t/ produced by the English monolingual group (77 ms).

Native English subjects who were more experienced in French showed more evidence of producing /t/ with a shorter VOT interval in French than English. The subjects in Group D produced /t/ with a VOT interval that was 13 ms shorter on average in French (43 ms) than in English /t/ (56 ms). The subjects in Group C produced /t/ with a mean VOT that was 26 ms shorter on average in French (46 ms) than English (72 ms).

Figure 1 shows that even subjects who were highly experienced in L2 did not produce the /t/ in their L2 like a native speaker. The native French subjects in Group E produced English /t/ with a shorter mean VOT (49 ms) than the English monolinguals (77 ms).

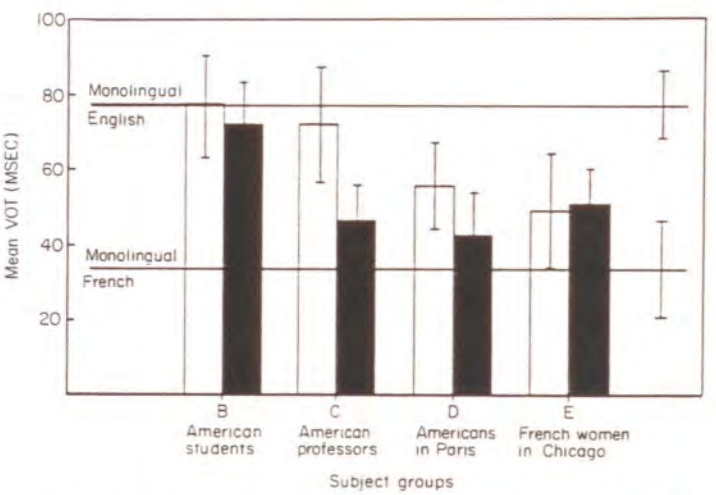

Figure 1. The mean voice onset time, in ms, in tokens of /t/ in *tous* (■) and *two* (□) by the L2 learners in four groups (represented by bars) and by monolingual native speakers of English and French (represented by horizontal lines). Most means are based on 70 observations (7 subjects × 2 conditions × 5 replicate tokens); the brackets enclose ±1 standard deviation.

Conversely, the native English subjects in Group C (46 ms) and Group D (43 ms) produced French /t/ with longer VOT values than the French monolingual subjects (33 ms).

Figure 1 shows that the magnitude of the VOT difference between French and English /t/ did not vary systematically with L2 experience. As expected, the native English subjects in Group C produced a larger French–English VOT difference (26 ms) than the relatively less experienced native English subjects in Group B (5 ms). One might have expected the native English subjects in Group D to produce an even larger French–English difference than the subjects in Group C owing to their much greater experience in French. Instead, they produced a *smaller* difference (13 ms). Similarly, one might have expected the native French subjects in Group E, who were as experienced in their L2 as the native English subjects in Group D, to produce a larger French–English difference than the subjects in Group C. However, they too produced a smaller French–English difference (2 ms).

Finally, Fig. 1 shows two effects of L2 learning on the production of /t/ in L1. The native French speakers of English in Group E produced French /t/ with longer, and therefore English-like, VOT values (51 ms) than the French monolingual (33 ms). The experienced native English speakers of French in Group D, conversely, produced English /t/ with considerably shorter, French-like, VOT values (49 ms) than the English monolinguals (77 ms). An L2 effect on the production of L1 stops was less pronounced, or not evident, for the less experienced native English subjects in Groups B and C.

The ANOVA examining production of English /t/ by the subjects in Groups A–E revealed a significant effect of Group [$F(4, 30) = 7.23$; $p < 0.001$]. The post-hoc comparisons indicated that the native French subjects produced English /t/ with significantly shorter VOT values than the English monolinguals. The native English subjects in Group D produced English /t/ with significantly shorter VOT values than the English monolinguals. However, the less experienced native English speakers of French in Groups B and C did not differ significantly from the English monolinguals in producing English /t/. The subjects in Group D (experienced native English speakers of French) and Group E (experienced native French speakers of English) produced English /t/ with VOT values that did not differ significantly. The means for both groups were intermediate to the means observed for the English and French monolinguals.

The Group × Language interaction in the ANOVA examining the VOT in English and French /t/ produced by the subjects in Groups B–E reached significance [$F(3, 24) = 8.07$; $p < 0.001$]. The simple main effect of Language was significant for the relatively experienced native English speakers of French in Groups C and D, but not for the least experienced native English subjects in Group B. The simple main effect of Group was significant for both English /t/ [$F(3, 52) = 12.1$, $p < 0.001$] and French /t/ [$F(3, 52) = 21.1$; $p < 0.001$]. The post-hoc comparisons revealed that the subjects in Groups B and C produced English /t/ with significantly longer VOT values than the subjects in Groups D and E. The post-hoc comparisons also revealed that the subjects in Group B produced French /t/ with significantly longer, and therefore English-like, VOT values than the native English subjects in Groups C and D, and the native French subjects in Group E.

The effect of Subject Group reached significance in the ANOVA examining French *tous* and *tu* [$F(4, 30) = 9.31$; $p < 0.001$], but not the Group × Word interaction. The post-hoc comparisons revealed that the least experienced native English speakers of French (Group B) produced French /t/ with significantly longer VOT values than the native English subjects in Groups C and D, and the French monolinguals. The native

English subjects in Group C produced French /t/ with significantly longer VOT values than the French monolinguals. The native French speakers of English (Group E), but not the native English subjects in Group D, also produced French /t/ with significantly longer, and therefore English-like, VOT values than the French monolinguals.

The subjects in four of the five subject groups produced /t/ with a longer mean VOT value in *tu* than *tous*. The magnitude of the effect averaged 8 ms. As a result, the effect of Word reached significance [$F(1, 30) = 15.0; p < 0.001$]. The VOT difference between *tu* and *tous* was probably caused by aerodynamic factors deriving from differences in the tongue position associated with the following vowel (/u/ or /y/), and will not be further discussed.

3.2. *Vowel production*

Flege & Hillenbrand (1984) found that F_2 frequency accounted for considerably more variance in listener's identification of French /u/ and /y/ than F_1 or F_3 frequency. Preliminary analyses of the vowel formant data also indicated that there were substantially greater differences between groups in F_2 frequency than in F_1 or F_3 frequencies. Therefore, the mean F_1 and F_3 values have been presented in Appendix 1, and the results of statistical tests summarized in Appendix 2. These results will not be further discussed.

Figure 2 uses bars to plot the mean F_2 values in tokens of French and English /u/ produced by the native English subjects in Groups B, C, and D, and by the native French subjects in Group E. The mean F_2 values obtained for French and English monolinguals are represented by horizontal lines. Inspection of this figure reveals that neither the native English speakers of French, nor the French speakers of English, produced /u/ in their L2 with F_2 values equaling those of the monolingual subjects used to define the phonetic norm of L2. The native English subjects in Groups B–D produced French /u/ with a mean F_2 frequency that was 450 Hz higher, and therefore more English-like, than the French monolinguals. The native French subjects seem to have more closely

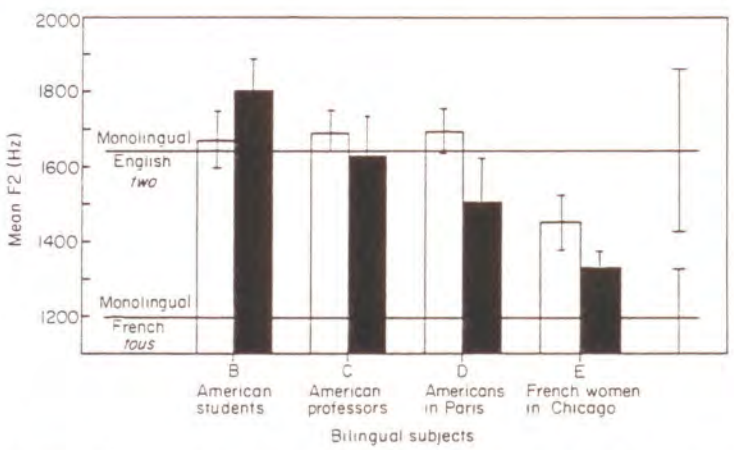

Figure 2. The mean F_2 frequency, in Hz, of the /u/ tokens in *tous* (■) and *two* (□) produced by L2 learners in four groups (represented by bars) and by monolingual native speakers of English and French (represented by horizontal lines). Most means are based on 70 observations; the brackets enclose ± 1 standard deviation.

approximated the phonetic norm for /u/ in their L2. They produced English with a mean F_2 frequency that was only about 200 Hz lower, and therefore French-like, than the English monolinguals.

To produce French /u/ authentically, a native English speaker would need to realize /u/ with much lower F_2 frequencies than in English. The shift would need to average about 450 Hz for adult females, according to the values obtained here for English and French monolinguals. The least experienced native English subjects examined here (Group B) clearly did not produce French /u/ authentically, at least insofar as can be determined through simple acoustic measurements. In fact, instead of approximating the French phonetic norm by lowering the F_2 in /u/, they produced /u/ with a higher mean F_2 frequency in French (1802 Hz) than English (1670 Hz). This suggests that the Group B subjects did not produce the French word *tous* with an English /u/, but instead may have confused the identity of the vowel in *tous* and attempted to produce /y/ rather than /u/.

There was no evidence that the more experienced native English subjects in Group C approximated the F_2 norm of French for /u/. They produced /u/ with about the same F_2 frequency in French (1630 Hz) and English (1688 Hz). The native English subjects in Group D did show evidence of approximating French phonetic norms. They produced /u/ with a lower mean F_2 value in French (1508 Hz) than English (1693 Hz). The native French subjects in Group E also showed some evidence of approximating the phonetic norm of their L2. They realized /u/ with a higher mean F_2 frequency in English (1454 Hz) than French (1333 Hz).

Figure 3 plots the mean F_2 frequency of French /u/ and /y/ produced by the subjects in Groups B–F. The systematic decrease evident in the F_2 frequencies of French /u/ across the five groups was not evident for French /y/, which showed more nearly constant F_2 frequencies. As a result, there were important differences between groups

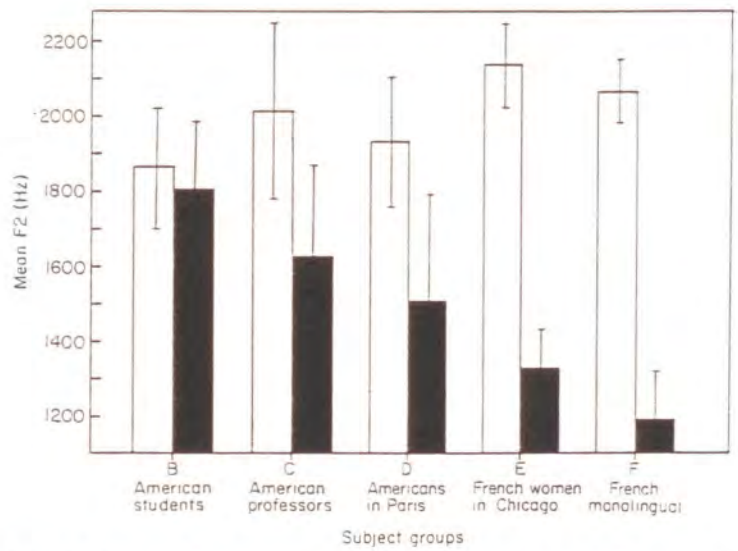

Figure 3. The mean F_2 frequency, in Hz, in tokens of /u/ in *tous* (■) and /y/ in *tu* (□) produced by four groups of L2 learners and a group of monolingual speakers of French. Most mean are based on 70 observations; the brackets enclose ±1 standard deviation.

in the magnitude of the F_2 difference between French /u/ and /y/. The French monolinguals produced a substantial F_2 difference between /y/ (2062 Hz) and /u/ (1196 Hz), albeit a smaller difference (866 Hz) than that observed by Debrock & Forrez (1976) for French monolinguals (1201 Hz). The native French subjects who spoke English (Group E) produced an /u/ − /y/ difference that was only slightly smaller (785 Hz) than the French monolinguals'. The native English subjects in Groups B–D produced smaller /u/ − /y/ differences that appeared to be related to French-language experience. The subjects in Group D produced a mean 422 Hz difference; the subjects in Group C produced a mean 379 Hz difference; and the subjects in Group B a mere 61 Hz difference.

One would expect the native English speakers of French to produce English /u/ with lower, French-like, F_2 values than English monolinguals if learning similar L2 vowels affected their production of vowels in L1. Conversely, one would expect the French speakers to produce French /u/ with higher, English-like, F_2 values than French monolinguals. Learning French did not seem to affect production of English /u/ by the native English subjects in Groups B–D (see Fig. 2). They produced English /u/ with mean F_2 frequencies that were on average slightly higher (1684 Hz) than those of the English monolinguals (1646 Hz). However, learning English *did* seem to affect how the native French subjects in Group E produced /u/ in their L1. These subjects produced French /u/ with a mean F_2 frequency that was, as expected, somewhat higher (1333 Hz) than the value obtained for the French monolingual subjects (1196 Hz).

The effect of Group in the ANOVA examining the production of English /u/ by the subjects in Groups A–E did not reach significance [$F(4, 30) = 2.14$; ns], even though the native French subjects in Group E produced English /u/ with a mean F_2 frequency that was about 200 Hz lower than that observed for all four native English groups (A–D).

However, the effect of Group did reach significance [$F(3, 24) = 6.98$; $p < 0.01$] in the ANOVA examining production of French and English /u/. The Group × Language interaction was non-significant [$F(3, 24) = 2.03$; n.s.]. Post-hoc comparisons revealed that the native French subjects in Group E produced /u/ (in French and English words) with significantly lower F_2 values than the native English subjects in Groups B–D.

The ANOVA examining the F_2 frequencies in French *tous* and *tu* revealed a significant Group × Word interaction [$F(4, 30) = 15.6$; $p < 0.001$]. The simple main effect of Group was significant for *tous* [$F(4, 65) = 18.5$; $p < 0.001$] and for *tu* [$F(4, 65) = 5.12$, $p < 0.001$]. The post-hoc comparisons indicated that the native English subjects in Group B produced *tous* with a significantly higher (English-like) mean F_2 frequencies than the subjects in Groups D–F; the native English subjects in Group C produced it with significantly higher mean F_2 frequencies than the subjects in Groups E and F; and the native English subjects in Group D produced it with higher mean F_2 frequencies than the subjects in Group F. Although the native French subjects in Group E produced *tous* (/tu/) with a mean F_2 frequency that averaged 137 Hz higher (and therefore more English-like) than the French monolinguals, the difference was non-significant.

The post-hoc comparisons revealed that the native English subjects in Group B produced *tu* (/ty/) with a lower mean F_2 than the French monolinguals. No other between-group difference for *tu* reached significance.

4. Discussion

The study examined the production of "new" and "similar" phones in a foreign language (L2). A *similar L2 phone* was defined as an L2 phone which is realized in an acoustically

different manner than an easily identifiable counterpart in L1. A *new phone*, on the other hand, was defined as an L2 phone which does not have a counterpart in L1, and may therefore not be judged as being the realization of an L1 category (see Introduction). The data presented here support the hypothesis (Flege & Hillenbrand, 1984) that an upper limit exists on the extent to which L2 learners approximate the phonetic norms of the L2 for similar but not new phones.

There was a clear difference in the extent to which native speakers of English approximated the phonetic norm of French when producing the similar L2 vowel /u/ but not the new L2 vowel /y/. The subjects in all three native English groups, which differed considerably according to French-language experience, produced French /y/ with only slightly lower mean F_2 frequencies (1934 Hz) than a group of French monolingual subjects (2062 Hz). Only the least experienced of the three groups of native English subjects differed significantly from the French monolinguals. However, the subjects in all three native English groups, including those who had been living in Paris for 12 years, produced French /u/ with mean F_2 frequencies that were significantly higher, and therefore English-like, than the French monolinguals (1196 Hz).

The subjects in two native English groups showed no evidence of approximating the F_2 norm of French for /u/. The least experienced native English subjects (Group B) produced /u/ with a higher (by 132 Hz), rather than lower, mean F_2 frequency in French than English. The mean F_2 frequency they produced in French /u/ was also higher (by 156 Hz) than the F_2 produced in English /u/ by a group of English monolinguals. The more experienced native English subjects in Group C seemed to substitute English /u/ for French /u/. They produced French /u/ with F_2 values that were nearly identical to the F_2 values produced in English /u/ by the English monolinguals (1646 Hz). Since they did not modify their production of /u/ when switching from English to French, their French /u/ had a substantially higher (by 434 Hz) mean F_2 frequency than the /u/ produced by French monolinguals. Only the most experienced native English subjects (Group D) approximated the F_2 norm of French for /u/. However, even they produced French /u/ with a higher, and therefore English-like, mean F_2 frequency (1508 Hz) than the French monolinguals. And even they showed only a minimal decrease in mean F_2 frequency 185 Hz) when switching from English to French.

English /u/ was a similar L2 vowel for the native French subjects examined here. These subjects had about the same amount of L2 experience as the most experienced native English subjects (i.e. about 12 years in an L2-speaking environment). They were, therefore, expected to approximate the phonetic norm of English for /u/ to the same extent as the most experienced native English group approximated French phonetic norms for French /u/. In fact, they seemed to have produced /u/ in their L2 somewhat more authentically. Their English /u/ had a mean F_2 frequency (1454 Hz) that was considerably higher than F_2 in the /u/ of French monolinguals (1196 Hz), and a non-significant F_2 200 Hz lower than F_2 in the /u/ of English monolinguals (1646 Hz).

The lack of a significant difference between the native French subjects and the English monolinguals should probably not be regarded as a disconfirmation of the hypothesis (Flege & Hillenbrand, 1984) that L2 learners will not achieve the L2 phonetic norm for similar phones. The native French subjects increased the F_2 frequency in /u/ by only an average of 121 Hz when switching from French to English. There appears to be much greater variation in the F_2 values in American English /u/ (Labov, 1981) than for French /u/ (owing to the absence of an /y/, which sets an upper limit on the F_2 values that can

be produced in French /u/ without creating perceptual confusions). It is not necessarily the case that the English monolinguals examined here produced /u/ in the same way as the English speakers encountered by the subjects in Group E. Although highly speculative, it is possible that the French monolinguals would have differed significantly from another group of monolingual English subjects. This represents an important methodological problem for any phonetic study which makes use of the notion "phonetic norm".

There was little evidence that learning French significantly influenced how the native English speakers produced /u/ in English. Their realizations of English /u/ had mean F_2 frequencies that were slightly higher on average (40 Hz higher), rather than lower, than the English monolinguals'. None of the three native English groups differed significantly from the English monolinguals. The native French speakers showed a non-significant trend in the expected direction, producing French /u/ with a mean F_2 frequency that was 137 Hz higher, and therefore more English-like, than the French monolinguals.

Owing to the differences in /u/ production just mentioned, there were some striking differences between subject groups in terms of the magnitude of the F_2 contrast between French /y/ and /u/. The French monolinguals produced a 866 Hz difference, and the native French speakers of English produced a 785 Hz difference. The native English subjects produced much smaller F_2 differences between French /y/ and /u/. These differences ranged from a non-significant 61 Hz difference, for the least experienced native English subjects (Group B), to significant 379 and 422 Hz differences for the more experienced English groups (C and D, respectively).

The data suggest that native English speakers who are just beginning to learn French as an L2 may confuse the /u and /y/ categories of French (see also Gaudin, 1953; Walz, 1979; Le Bras, 1981). This would explain why the subjects in Group B not only did not approximate the F_2 norm of French for /u/, but actually produced it with higher frequencies than English /u/. French /y/ is realized with higher F_2 values than French /u/, which means that it tends to resemble English /u/. Moreover, English /u/ is realized as an [y]-quality vowel in certain phonetic contexts. This issue should be explored in future research examining the perceptual similarity of French vowels, English vowels, and (above all) French and English vowels.

Previous studies of L2 speech production have shown that adults who learn English as an L2 typically produce English stops with significantly shorter VOT values than native English speakers if the stops /p, t, k/ are implemented as short-lag stops in their L1 (e.g. Suomi, 1976; Flege, 1980; Flege & Port, 1981; Flege & Hillenbrand, 1984). This was true of the native French subjects examined here, despite the fact that they had lived in Chicago for about 12 years and used English as their principal language at the time of the study. They produced English /t/ with a mean VOT that was significantly shorter (by 30 ms) than the English monolinguals. Conversely, the native English subjects produced French /t/ with longer, and therefore English-like, VOT values than the French monolinguals. The subjects who had the least amount of French-language experience (Group B) produced French /t/ with a mean VOT value that differed little (71 ms) from the mean observed for English /t/ as spoken by English monolinguals. Those with greater experience in French (Group C) more closely approximated the French phonetic norm for /t/ (52 ms), but nonetheless differed significantly from French monolinguals.

The most experienced native English group (Group D) did not, however, differ significantly from the French monolinguals. On the surface, at least, this seems to represent a serious challenge to the strong claim (Flege and Hillenbrand, 1984) that even

highly experienced L2 learners will differ from native speakers in producing similar L2 phones. However, there are reasons for doubting that the native English subjects in Group D actually "achieved" the French VOT norm for /t/. The /t/ of French has been described in previous research as being a short-lag stop with VOT values of less than 30–35 ms (Caramazza & Yeni-Komshian, 1974; Serniclaes, Alimonte & Alegria, 1984). The subjects in the most experienced native English group produced French /t/ with a mean of 47 ms. The shortest mean observed for any of them was longer (39 ms) than the mean value observed for the French monolingual group (38 ms).

The mean for the French monolinguals appears to have been inflated by the values obtained for two subjects who produced /t/ with long-lag VOT values averaging 49 and 63 ms. Social psychologists have documented the tendency of talkers to adapt their speech to that of an interlocuter (Giles, Taylor & Bourhis, 1973; Thakerar, Giles & Cheshire, 1982). The author elicited production data from the French monolinguals in obviously English-accented French. His speech was likely to have contained tokens of /t/ produced with English-like VOT values. It is possible that the two French monolinguals just mentioned accommodated their speech to the author's by increasing the VOT values when realizing French /t/. Although speculative, this hypothesis appears to be plausible in light of the finding by Flege & Hammond (1982) that monolingual subjects who had been exposed to non-native speakers were able to modify the VOT interval in /t/ when asked to mimick the foreign accent of the non-native speakers.

The observation that the native French and English subjects produced L2 stops with VOT values that tended to resemble values typical for their L1 might be regarded as examples of "interference" (Flege & Davidian, 1985). The data for /u/ are also consistent with the view that the patterns of segmental articulation established in L1 acquisition are maintained in the production of an L2. The problem with invoking "interference" as an explanation for the data presented here and in other L2 production studies is the need to understand why experienced L2 learners seem to approximate, but not achieve, the phonetic norm of L2 for similar L2 phones.

In this study we saw that the most experienced native English subjects produced French /t/ with significantly longer (and therefore more English-like) VOT values than less experienced native English subjects. This must mean that they had noted at least some of the acoustic differences distinguishing French and English /t/, and had learned something about how to realize those differences articulatorily. Flege (1980) suggested that it may be just as important to explain why complete learning does not occur as it is to explain the partial approximation that is often observed in L2 production studies.

An explanation for the partial approximation of L2 phonetic norms for similar L2 phones may be evident in the L1 production data presented here. They supported the hypothesis that learning an L2 influences how phones are realized in L1. The most experienced native English subjects, and the equally experienced native French subjects, produced /t/ in their L1 with VOT values that differed significantly from those observed for monolingual subjects. The French subjects produced French /t/ with longer, English-like VOT values; and the English subjects produced English /t/ with shorter, French-like VOT values.

This finding undermines the view that interference and "universal" effects on production deriving from the nature of the speech production mechanism are the only factors which directly influence how authentically L2 phones are produced (Lado, 1957; Brière, 1966; Weinreich, 1968; Valdman, 1976). It might be easier physiologically to produce short-lag stops (Kewley-Port & Preston, 1974). If so, the native English speakers

of French may have produced English stops with shortened VOT values because L2 learners manifest "universal" tendencies in their speech production. However, such an explanation could not be used to explain the opposite effect observed for the native French subjects.

"Interference" implies a unidirectional effect of L1 on L2. But what we saw here for /t/ was clearly a bi-directional effect. An important underlying assumption of this study was that the French and English subjects would judge to be phonetically equivalent the [t] and [t^h] phones used by French and English monolinguals, respectively, to realize /t/. The results showed that the /t/ of French and English mutually influenced one another. This suggests that the central phonetic representation for /t/ of the experienced L2 learners underwent restructuring or modification as the result of exposure to acoustically different phones in L1 and L2 that were judged to be realizations of a single phonetic category. If French [t] and English [t^h] phones were not judged to be equivalent, it would be difficult to explain the convergence of VOT in French and English stops to mean values that were intermediate to those observed for French and English monolinguals.

The "merging" of the phonetic properties of similar L1 and L2 phones might account for what appears to be an upper limit on phonetic approximation for similar L2 phones. If equivalence classification prevents L2 learners from developing a separate phonetic category for similar L2 phones, they may be unable to produce similar phones in L2 and L1 authentically because they need to implement /t/ in both L2 and L1 using the same phonetic category. (See Keating, 1984, for a discussion of the difference between phonetic "implementation" and "realization".)

The merger hypothesis is consistent with the observation that the native French subjects produced /t/ with VOT values in L1 and L2 that were intermediate to the values observed for monolingual native speakers of French and English. These subjects did not produce a significant difference between /t/ in English and French, despite the fact that they had used English as their principal language in an English-speaking environment for about 12 years.

However, the subjects in the two most experienced native English groups did produce /t/ with significantly different VOT values in English and French. These cross-language differences may have been achieved by using different realization rules with which to produce /t/ in French and English. Such realization rules are already needed to account for the ability of monolinguals to realize the same categories differently in various social contexts (e.g. Labov, 1981).

In summary, the results presented here indicated that adults are capable of learning to produce new phones in an L2, and of modifying their previously established patterns of articulation when producing similar L2 phones. It appears that the mechanism of equivalence classification leads them to identify acoustically different phones in L1 and L2 as belonging to the same category. This may ultimately prevent them from producing similar but now new phones authentically.

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Appendix 1

Mean F_1 (upper panel) and F_2 (lower panel) frequencies, in Hz, of /u/ in English *two* and French *tous*, and of /y/ in French *tu*, produced in two speaking conditions by subjects in six groups. Each mean is based on the mean for seven subjects which, in turn, was based on the mean of five measurements in most instances (see text); inter-subject standard deviations are in parentheses.

		Subject Group					
Word	Condition	A	B	C	D	E	F
two	Phrase	232	271	253	317	257	—
		(16)	(40)	(21)	(58)	(47)	
	Sentence	251	283	257	320	270	—
		(16)	(46)	(14)	(48)	(38)	
tous	Phrase	—	257	258	288	262	305
			(60)	(26)	(25)	(37)	(24)

Word	Condition	Subject Group A	B	C	D	E	F
	Sentence	—	248	254	309	271	304
			(35)	(22)	(35)	(65)	(28)
tu	Phrase	—	250	260	290	252	283
			(55)	(21)	(42)	(18)	(38)
	Sentence	—	254	236	275	250	270
			(58)	(28)	(17)	(26)	(27)
two	Phrase	2570	2733	2650	2694	2548	—
		(196)	(254)	(197)	(133)	(153)	
	Sentence	2729	2765	2623	2703	2546	—
		(115)	(333)	(195)	(155)	(166)	
tous	Phrase	—	2716	2616	2656	2464	2636
			(175)	(180)	(105)	(121)	(314)
	Sentence	—	2695	2589	2722	2454	2709
			(174)	(171)	(149)	(156)	(243)
tu	Phrase	—	2874	2675	2598	2778	2642
			(124)	(257)	(78)	(189)	(150)
	Sentence	—	2878	2737	2605	2884	2760
			(308)	(250)	(77)	(252)	(152)

Appendix 2

The subjects in Group D produced English /u/ with F_1 values averaging 318 Hz, which is very close to the mean value of 314 Hz reported previously for female monolingual native speakers of French (Debrock & Forrez, 1976), but higher than that observed here for the native French subjects in Group E (263 Hz) or for the native English subjects in Group A, B and C (258 Hz). The ANOVA examining F_1 frequency in English /u/ produced by subjects in Groups A–E indicated a significant effect of group [$F(4, 30) = 4.86$; $p < 0.01$]. Post-hoc comparisons revealed that the subjects in Group D produced English /u/ with significantly higher F_1 values than those in Groups A, B, C and E. Other ANOVAs indicated that the effect of group on F_3 was always non-significant ($p < 0.05$). The ANOVAs examining production of /u/ in *tous* and *two* by subjects in Groups B–E revealed there were no significant between-group differences in F_1 frequency [$F(3, 24) = 3.21$; $p < 0.05$] or F_3 frequency [$F(3, 24) = 3.59$; $p < 0.05$], nor any other significant main effect or interaction for F_1 or F_3. The same held true for ANOVAs examining production of French *tous* and *tu* by the subjects in Groups B–F.