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Bilinguals play by the rules: perceptual compensation for assimilation in late L2-learners

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Abstract

Phonological rules introduce variation in word forms that listeners have to compensate for. We previously showed (Darcy 2002; Darcy et al., to appear) that compensation for phonological variation in perception is driven by language-specific mechanisms. In particular, English speakers compensate more for place assimilation than for voicing assimilation, whereas the reverse holds for French speakers. English indeed has a rule of place assimilation, whereas French has a rule of voicing assimilation. In the present study, we explore the patterns of compensation for assimilation in English learners of French and in French learners of English. We use the same design and stimuli as Darcy (2006), Darcy et al. (to appear); in this design, listeners are engaged in a word detection task on sentences containing occurrences of both place assimilation and voicing assimilation. We test British English and American English learners of French as well as French learners of American English on both their native language (L1) and their second language (L2). The results show that beginners interpret their L2 in exactly the same way as their L1: they apply the native compensation pattern to both languages. Advanced learners, by contrast, succeed in compensating for the non-native assimilation rule in their L2, while keeping the native compensation pattern for L1; as little or no interference from L2 on L1 is observed for these learners, we conclude that two separate systems of compensation for phonological processes can co-exist.

1. Introduction

The word recognition system copes easily with the great variability of spoken language. One source for this variability comes from the mutual influence of sounds at word edges, resulting in assimilation: one sound takes over some properties of the neighbor sound. Such cases obscure the direct relationship between a word's surface form and its identity, and make word recognition harder. Indeed, in order to recover from the change and activate the right word representation, assimilation processes have to be compensated for by the word recognition system. This paper addresses the issue of whether late learners compensate for an assimilation rule that is not present in their native language.

1.1. Language-specific compensation for phonological processes

Assimilation processes alter segments at word boundaries. For instance, French has a tendency towards regressive voicing assimilation, whereas English has a tendency towards regressive assimilation of place of articulation. In French for example, a word like *botte* [bot] 'boot' is produced as [bod] when it is followed by *grise* [griz] 'grey' (*bo[**dg**]rise*), but not when it is followed by *mauve* [mov] 'purple' (*bo[**tm**]auve*). French voicing assimilation applies to obstruent clusters inside the same phonological phrase, and propagates the voicing feature (voiced or unvoiced) of the second segment onto the first one. The initial m of *mauve* is not an obstruent, hence it does not trigger assimilation on the last consonant of *botte*. Similarly, in English, assimilation concerns coronals (t, d and n), which adjust their place of articulation to that of any following labial or velar segment. For example, the word *sweet*, if followed by *melon*, may assimilate the labial place of articulation, and be pronounced as *swee[**pm**]elon*. A word like *grapes* would equally alter the final coronal of *sweet*, which would become velar (*swee[**kg**]rapes*). The adjustments of phonological structure made by such processes are specific to a particular language. Such modifications occur at word boundaries: the form of a word may vary depending on the words surrounding it. Consequently, they are a problem for word recognition, and have to be learned specifically for each language.

Listeners have been shown to compensate for the assimilation processes that occur in their native language in a very precise way. Using different methods and contrasts, researchers have shown that listeners compensate only for those changes which correspond to existing processes in the language, and not for others (Coenen, Zwitserlood and Bölte,2001; Darcy 2002; Darcy et al. to appear; Gaskell and Marslen-Wilson 1996; 1998; 2001; Gow 2001; 2002; Koster 1987; Mitterer and Blomert 2003. See Darcy 2006 for a review). In one such study (Gaskell and Marslen-Wilson 1998), when presented with a changed word (*freigh[p]*), listeners were able to detect the target phoneme /t/ only when that changed word was followed by a context legitimating the change as assimilation (for example, in the phrase *freight bearer* : *freigh[pb]earer*). They failed to detect /t/ in the phrase *freight carrier* where the change is rendered inappropriate (unviable) by the context (*freigh[pk]arier*). Here, the change does not correspond to any existing rule in English, and is not compensated for by native listeners of English. Gow's research (2003), by contrast, has shown that compensation may occur even for changes which do not reflect an existing process in the language: he observed priming for a coronal-ending-word when followed by a labial (lexical decision priming for *cone* when hearing *co*$[^{n}_{m}]$ *bent*), which corresponds to the place assimilation process in English. He also observed comparable priming towards a labial word (*comb*) when a target ambiguous between *cone* and *comb* was followed by a coronal context (*co*$[^{n}_{m}]$ *dents*). Notably, the changes he used were doubly articulated segments retaining both place cues. In this case, listeners attribute multiple cues to different segmental positions (feature parsing). However, the priming effect towards *comb* in the case of labial to coronal assimilation may be due to the fact the labial cue points towards a lexical competitor. It is not clear what would happen if parsing these multiple cues would not give rise to such a possibility (when there would be no lexical competitor).

This case was explored in Darcy et al. (to appear; see also Darcy, 2006) using a word detection task, where American and French listeners were presented to different kinds of alteration on target words, corresponding or not to an existent assimilation process in their native language: Sentences for each language provided examples of both the English place assimilation process and of the French voicing assimilation process. Changes were deliberate, i.e., they were not retaining multiple place or voicing cues in articulation, and they did not produce actual lexical competitors, but non-words.[1]

When hearing their native language, listeners compensated more for the native process than for the non-native one. French subjects, for instance, detected the target [bɔt] more often in *bo[dg]rise* than in *bo[dm]auve*, compensating for voicing assimilation when appropriate, whereas they did respond less to the target *lune* [lyn] 'moon' in both conditions (appropriate) *lu[mp]ale* and (inappropriate) *lu[mʀ]ousse*, hence correctly rejecting a place assimilated target, independently of the context condition. Similarly, American English listeners detected appropriately assimilated targets only in the native case, i.e. for place assimilation. Their detection of voiced assimilated targets was significantly less important for both the appropriate and the inappropriate context.

One of the most striking conclusions of the Darcy et al. study is that compensation for assimilation reflects language-specific phonological knowledge. This raises the question to what extent adult learners are able, when they are faced with a second language and a different phonological system, to learn these phonological competences for purposes of processing L2, and in case they do learn, to what extent does this learning influence their L1-phonological knowledge.

1.2. Acquisition of phonological processes

We briefly consider some of the contradictory evidence on late learners' acquisition of phonology, represented in two main views: on one hand, phonological properties of the target language are considered to be very difficult to acquire. A large body of evidence in second language learning suggests that phonological properties are difficult to learn, even in learners who were exposed to the new phonological system early in life. Flege, Yeni-Komshian and Liu (1999), for example, have shown that listeners were able to detect a slight foreign accent in Korean learners who arrived in the USA as early as 1 year of age. Similarly, Pallier et al. (1997) showed that Catalan-Spanish bilinguals who were born in a monolingual family but immersed in a bilingual culture from age 4 still have problems in perceiving aspects of their non-native phonologies.

This difficulty is either attributed to maturational factors (critical period hypothesis, applying to other linguistic domains also, Long 1990; Flege 1995; Flege, Munro and MacKay 1995; Flege, Yeni-Komshian and Liu 1999; Johnson and Newport 1989; Weber-Fox and Neville 1996), or to interference/competition effects between L1 and L2 (Flege, Frieda and Nozawa 1997) : When faced with a non-native phonological system, the non-native listener would process the input using L1's phonological system, thereby showing intrusion of L1 into L2 processing. This is among others personified as the Perceptual Assimilation Model (PAM, Best 1995), i.e. a perceptual assimilation of the non-native phonetic categories to those of L1 (e.g., Kuhl 1991; Flege 1995). This assimilation has been shown in a number of different studies (McAllister, Flege and Piske 2002; Strange et al. 1998; Hallé, Best and Levitt 1999; Weber and Cutler 2004).

On the other hand, there is also some evidence showing that experience in a second language (e.g., as measured by proficiency) modifies the native speech perception (Flege, Bohn and Jang 1997; Weber 2001), and even short exposure to ambiguous sounds in a specific context may provoke a category boundary shift (Norris, McQueen, and Cutler 2003). Examples such as these could be interpreted as evidence for the malleability of phonological knowledge, which allows for modifications through L2 exposure. In some cases, even native attainment in phonology has been reported, based mainly on observations made in the domain of foreign accent judgments in production of non-native speakers (Bongaerts 1999, Bongaerts, Mennen and van der Slik 2000; Flege, Yeni-Komshian and Liu 1999).

1.3. The present study

So far, little work has been done specifically on the acquisition of phonological processes. What would native speakers of English learning

French do when they process French sentences? We use the same design and stimuli as in Darcy et al. (to appear). In Experiment 1, we report the results of two groups of British English native speakers hearing French sentences. The first group consists of beginning learners of French, whereas the second group is more experienced. In Experiment 2, we extend the exploration of learners' compensation patterns for assimilation using a crossover design. We test American learners of French and French learners of American English on both their first and second language. This series of experiments allows us to address how learners represent the phonological system of L2. This is an important issue for better understanding how words are recognized in a foreign language, and how different languages are represented in a learner's brain.

In principle, there are three possibilities: First, participants might apply the same behavior as in L1 (more compensation for the native process over the non-native one) when hearing L2. In this case, they would fail to detect correctly assimilated words in that language, but detect those which are inappropriately modified as being acceptable variants of the target word. In other words, if compensation is not adaptable to L2 processes, listeners will compensate in both languages for changes native in L1. In this case, the phonological system is not modifiable and proficiency in L2 does not play any role.

Second, listeners might be able to learn the processes applying in L2, but if this learning is only extending the L1 phonological system, the prediction is that more advanced learners would apply compensation to both the native and non-native process in L1 and L2. Therefore, they would detect appropriately assimilated words according to both the native and non-native process, for both languages.

These two possibilities would not prevent the overapplication of L1 rules in L2 processing. In the second case, the newly acquired L2 processes would also alter the first language system, in the same way as phonetic categories for L1 and L2 sharing the same space influence each other.

It is only when this learning is combined with the possibility to build separate systems that a native-like compensation pattern would be possible in both tested languages. In this case, when hearing L2, highly proficient learners would detect the correctly assimilated tokens, and correctly reject the inappropriately assimilated ones according to L2 phonology, thus showing the same pattern as native listeners of that language.

2. Experiment 1 : English hearing French

2.1. Method

2.1.1. Stimuli

The stimuli used in all experiments presented in this paper are those described in Darcy et al. (to appear). The French and the American English stimuli were identical in design and conditions. We describe here the construction of French stimuli only: Thirty-two target items were selected. They are all French monosyllabic nouns, with a C(C)VC structure. Each target (e.g., “robe”) is modified on its last consonant according to the voicing or place feature and ends up with 2 forms, the “original” and the “changed” form, which is always a non-word (nw), e.g., /rob/ vs. $/rop/_{nw}$. The target in its “original” or in its “changed” form is then paired to three different context words (adjectives, for French),[2] producing three different conditions. The following table illustrates these conditions with two examples, for voicing “robe” (‘dress’), and for place “lune” (‘moon’).

Table 1. Overview of context conditions and changes for French stimuli. Here, voicing assimilation is the native process, whereas place assimilation is non-native. For English stimuli, this pattern is reversed.

	Type of change			
Condition	Native (voicing)		Non-native (place)	
	target “robe” [ʀɔb] ‘dress’		target “lune” [lyn] ‘moon’	
appropriate change (viable context)	1a	ro[**p**+s]ale ‘dirty dress’	2a	lu[**m**+p]ale ‘pale moon’
non appropriate change (unviable context)	1b	ro[**p**+n]oire ‘black dress’	2b	lu[**m**+ʀ]ousse ‘red moon’
No-change	1c	ro[b+ʀ]ouge ‘red dress’	2c	lu[n+ʒ]aune ‘yellow moon’

The changed form (a non-word) is associated with 2 context words whose initial consonant either does trigger assimilation (e.g., 1a and 2a, for voicing or place respectively), or does *not* trigger them (e.g., 1b and 2b). Trigger contexts (for 1a and 2a) for voicing are obstruents agreeing in voicing with the changed form's final consonant, for place, they agree in place (labial or velar). The unchanged target (baseline c: no-change condition) is paired to a third context word and does not undergo assimilation (1c and 2c). Conditions a and b share the same target form (changed form), but differ in the context. If the context is a trigger, the change is appropriate (condition a: viable context condition); if it is not, the change is consequently not appropriate (condition b: unviable context condition). Conditions b and c on the other hand share the same kind of context, but differ in the form of the target (changed vs. non changed).

The whole stimuli set consists of two sets of 16 target items: the Voicing Set and the Place Set, that are matched in average frequency (voicing: 48.3, place: 42.3, $t(15)=-0.9$, $p>.1$)[3] (items for both languages are listed in Darcy 2006). In the Voicing Set, all 16 targets end in a final obstruent (voiced for half of the items and unvoiced for the other half). Their changed forms (16 matched non-words) were constructed by switching the voicing feature of the final obstruents (e.g. *robe* /rob/ 'dress' - *rope* $/\text{rop}/_{[nw]}$, or *lac* /lak/ 'lake' - *lague* $/\text{lag}/_{[nw]}$). In the Place Set, all final consonants are coronal; half are nasals and half are stops. 16 matched non-words were obtained by a change in the place feature of the final consonant (12 towards labial, 4 towards velar, e.g. *lune* /lyn/ 'moon' - *lume* $/\text{lym}/_{[nw]}$ or *boite* /bwat/ 'box' - *boike* $/\text{bwak}/_{[nw]}$).

Next, the three pairs "target form – context word" associated with each target item are embedded in three sentence frames (i.e., a sentence beginning and ending), where each of the three pairs may be inserted and results in a plausible sentence (e.g., for the item "robe", one of the three sentences is *Elle a mis sa* ___ ___ *aujourd'hui* 'she put on her ___ ___ today', where the three pairs 1a, 1b and 1c from Table 1 are inserted). Globally, the sentence frames are matched in number of words and position of the insertion slots across the Voicing Set and the Place Set. Combining pairs and frames gives rise to nine sentences associated with each item. We thus obtain 32 targets x 3 pairs x 3 frames = 288 actual sentences in total.

For purposes of counterbalancing, we defined three experimental lists. In each list, all three conditions are present for each item, but in different sentence frames. These are rotated across the three lists, so that across the experimental lists all three conditions appear in all three sentence frames. 30 additional filler sentences were constructed similarly to the experimental sentences. They are associated with target items that appear in an identical or changed form (one phoneme different) in the sentence. These filler sentences do not include any case of viable or unviable assimilation (voicing or place), and serve as training (N=18), or distractors (N=12).

For recordings of stimuli, all sentences were printed in a list. For French, the 288 test, 12 filler and 18 training sentences were recorded by the first author, a female native speaker of French. Our American English speaker was a woman from New Haven (CT). Changes were rendered orthographically in the sentences (e.g. for /rop/$_{[nw]}$, the printed sentence was "elle a mis sa **rope** sale").[4] The two native speakers were trained to pronounce the changed form of targets in a similarly natural way as the unchanged form (producing minimal pairs differing on the last phoneme), until they were familiar with all sentences. All materials for each language were recorded in a single session. The speaker was instructed to pronounce sentences in a fast speech rate, with maximal naturalness, and without emphasis on changed segments or on the preceding vowels. Within the critical sequences C+C [target's final consonant + context-word's initial], the first consonant was never released orally. Intonation was kept the same for all sentences of each frame. All sentences were recorded as a whole, several times. All stimuli were digitized at 16, kHz and 16 bits on an OROSAU22 sound board, and edited. All corresponding target words ("robe", "lune" etc., in their unchanged form) to be presented auditorily before each sentence were recorded by a male native speaker of French and English, respectively, and digitized. Finally, the set of 9 sentences per item which were most natural and where changes were clearest was manually selected according to ratings performed by two trained phoneticians.

For both languages, clarity of stimuli was validated by a separate experiment in a forced choice task on the last consonant of the target items in their changed or unchanged forms, with 18 native speakers of each language who participated only in the forced choice task experiment (for the validity of this measure, see Nolan 1992; Gaskell and Marslen-Wilson

1998). Target words and non-words were spliced out of all recorded sentences and presented without context in a list. For each form, subjects had to choose out of 2 alternatives which consonant they heard at its end. In isolation, all final consonants were perceived as the intended ones regardless of whether they were changed or unchanged and whether the change had been produced in a viable or unviable context.

2.1.2. Participants

In total, 46 native English speakers were tested in this experiment and paid for participation. Nineteen of them were tested in Paris, 27 in London. The 19 participants living in Paris were tested only on French sentences. However, the 27 Londoners were tested on both British English (reported in Darcy, 2006) and French sentences (in a single session). The London-group is homogenous: they were all native speakers of British English, raised monolingually in the south east of England. On average, they have had five years (SD 1.5) of French instruction, mostly at school (mean age of first exposure: 10.5, SD 1.5). None of them have had extensive exposure to French nor spent a long time living in France. The Parisian group of English listeners is less homogenous. Only four of them were raised in the south east of England. The others came from different origins (Ireland, Manchester, Scotland, Wales, United States, Australia). They all learned French at school, on average for 6.5 years (SD 2.2). Their mean age of first exposure is 11.1 years (SD 2.9). All were living in France (without explicit French instruction) for at least 12 months, 12 of them since more than 4 years. Their mean length of residence in France is 7.4 years (SD 8.8). Both groups are similar in terms of first exposure to French and length of instruction at school. None of the participants had previously taken part in a similar experiment, none reported any auditory deficits. They were paid for participation. Their subjective level of proficiency was assessed using a self rating scale, ranging from 1 (bad) to 10 (perfect). Each participant rated spontaneous speaking ability, comprehension and pronunciation. Evaluation scores are different for the London group and the Paris group: for the Parisian group, mean evaluation scores range from 7 to 10. The Londoner participants evaluation scores range from 2 to 6 (mean 3.5; SD 1.4). We therefore label the London-group as “beginning learners”, and the Paris-group as “advanced learners”. All participants reported having understood every sentence after the experiment.

2.1.3. Procedure

A test trial consists of a target word presented in isolation (male voice), followed after 500 ms of silence by a sentence (female voice). For the group tested in London (tested on both English and French), we used the same method for both languages: Participants have to press a “yes” or a “no” button as a response to the question “Do you think that the word presented alone is *the same* (i.e. has the *same form*) in the following sentence?” This instruction – together with a specific training – was given in order to draw their attention to the *goodness of pronunciation* of words in the sentence, i.e. to the *form* of words. For the same reason only a few filler words were included. The test phase was split into three blocks of 36 trials (32 test and 4 fillers) that were constructed such that a given test item appeared only once within each block. Trial order within blocks was randomized for each participant. The Parisian group was tested with the same method, except that instead of the “yes/no” response type used for the beginning learners, participants here had to press “yes” or refrain from pressing a button. This is the method used for French subjects hearing the same French sentences, in Experiment 1 of Darcy et al.

The experiment lasted 20 minutes. Participants were tested individually. Our main measure is the compensation index (formula 1) for each subject and item, computed on the basis of the number of yes-responses as a function of condition and contrast type (place vs. voicing).

$$\text{(1) Compensation index} = \frac{(\text{detection}_{\text{viable change}} - \text{detection}_{\text{unviable change}})}{(\text{detection}_{\text{no-change}} - \text{detection}_{\text{unviable change}})}$$

This index calculates the relative value of detection in the viable condition as a function of both other conditions. This allows us to obtain the ratio of “viable” to “no-change”, controlling for response biases or errors from the "unviable" condition. The index *x* thus corresponds to the degree of compensation for either place or voicing type of change.

2.2. Results

We present the results for each group, i.e. split according to proficiency. We applied the same criterion for item and participant rejection as in the Darcy et al. study, developed for native speakers hearing their native language: all items that yielded detection values higher than 50% in the unviable change condition (i.e., more than 50% false alarms) or less than 50% in the no-change condition (i.e., more than 50% misses) were excluded. For the learner groups hearing a foreign language, we decided to omit the same items that were excluded for the native speakers – here the French group hearing French. Thus one voicing item is excluded. The error rate for each participant is based on the performance on the no-change and unviable change conditions alone. Participants who made more than 37.5% errors (corresponding to the significance threshold in a Chi^2-test) for either the Voicing or the Place items were considered as failing to perform the word detection task for this contrast and were replaced. In the beginning learners group, four participants were excluded, as well as five advanced learners. We computed the compensation index for each participant and each item. Compensation indices are displayed in Fig. 1, for the group of beginning learners hearing English sentences (ALL, N=27) and French sentences (N=23), as well as for the group of advanced learners hearing French (N=14). For this and the following experiments, detection rates in place or voicing for each condition are summarized in the Appendix.

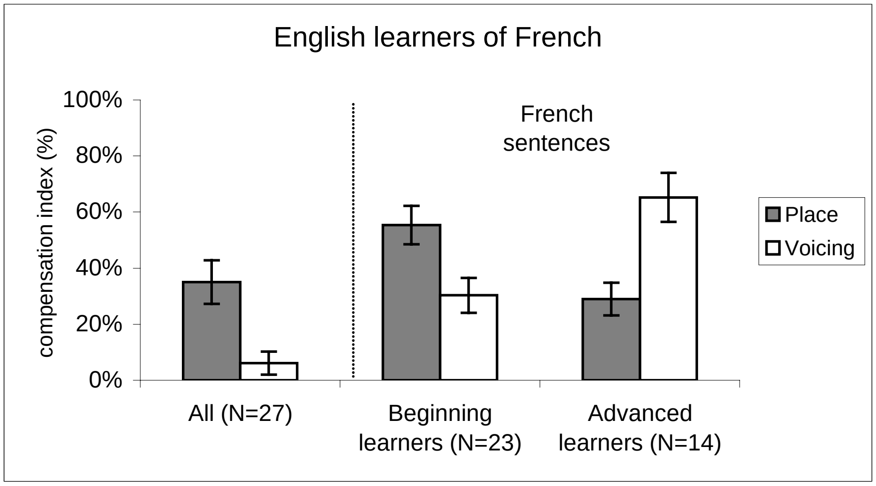

Figure 1. Compensation indices (%) for three groups of English listeners, hearing English sentences (N=27) and French sentences (beginning learners, N=23, and advanced learners, N=14).

For the beginner group, mean indices for place and voicing are 55% and 30%, respectively. Index means were used as the dependent variable in an ANOVA with Contrast (place vs. voicing) as a within-subject (respectively between-items) factor. The difference is significant by subjects, not by items because of high variability (standard error 0.16) on place items ($F_1[1,22]=11.4$, $p<.003$; $F_2[1,29]=1,8$, $p>.1$). This effect shows that all beginning learners, even when hearing French, compensate more for place assimilation than for voicing.

Advanced learners have a mean compensation index of 65% for voicing, and 28% for place. This difference is significant by subjects and items ($F_1[1,13]=12.1$, $p<.004$; $F_2[1,29]=17.3$, $p<.0001$), indicating that this group compensates more for voicing than place when hearing French.

Comparisons between these two groups reveal that on the same sentences, both groups behave in a different way, yet their pattern of compensation is reversed. An ANOVA on indices including both groups and declaring the factors Proficiency (beginning vs. advanced) and Contrast (place vs. voicing) revealed a significant interaction by subjects and by items ($F_1[1,35]=24.1$, $p<.0001$; $F_2[1,29]=12.9$, $p<.001$).[5] This means that proficiency may be responsible for the different response to place vs. voicing in both groups.

2.3. Discussion

In this experiment, we observed that two groups of subjects tested on the same sentences show a different pattern of compensation according to proficiency in a second language. The beginner group shows the same pattern they showed for their first language for French sentences as well, thus compensating more for a native process in their phonology than for a non-native one, independently of the language heard. They apply L1 phonology in L2 processing. By contrast, more advanced learners of French compensate more for the process which is native in L2, and less for a process they know from their first language. They behave like the French native listeners who hear French. They perceptually adapted their phonological system to the processes applying in French. This experiment allows us to reject the first hypothesis: compensation *is* adaptable to L2 processes, and this adaptation seems to be correlated to proficiency in that second language. In fact, correlation analysis on indices according to the length of residence in France for the advanced group was significant ($r=0.6$, $F[1,12]=7.1$, $p=.019$, higher index for voicing correlates to a longer stay in France).

Although Experiment 1 shows a differentiated pattern in the advanced group, there is no way to tell what their compensation pattern would look like in L1. Before we can determine whether there are two or only one system, according to our predictions above, we would have to directly compare the pattern of results of this highly proficient group on both French and English sentences. This was difficult due to the mixed origins of these participants and differences in testing methods for English and French sentences. In order to allow a direct comparison of participants' interpretation of alternations in a native and a second language, according to their proficiency in that second language, we decided to extend this study to other groups of late learners tested on both their first and second language.

3. Experiment 2

The combined results of experiment 1 on beginners and more advanced learners of French suggest that beginners tend to interpret assimilation alternations according to L1 phonology, but that more advanced learners do this according to L2 phonology, thus having a native-like compensation behavior in L2 (i.e. similar to native listeners of that L2). We aim to confirm this by first comparing compensation within the same subjects on both languages, and second, investigating the effect of proficiency in L2 on compensation pattern in each language.

3.1. Method and participants

3.1.1. General testing method

For all experiments including American and French late learners, stimuli are the same as in the Darcy et al. study, and were constructed as described in more detail above. The procedure is the same as described for the beginning learners in Experiment 1 of the present study: participants are requested to give a “yes/no” response. Before starting, they filled in a language background questionnaire. The experimenter assigned each participant to a group and, for those being tested on both languages within the same session (all except 10 French participants tested in Paris), fixed a language order. Instructions were given before each part in the tested language (completed orally if needed in the participant’s native language). The whole procedure lasted about 1 hour.

3.1.2. Biographical characteristics

In total, 58 subjects were tested in this study, 26 Americans (19 in Paris, 7 in the U.S.) and 32 French (10 in Paris, 22 in the U.S.). They were paid for participating and tested in their country of residence, either France (Paris) or the United States (Providence, RI; New Haven, CT; Amherst, MA). None of them had previously taken part in a similar experiment, nor reported any history of hearing disorders. None of them grew up bilingually. Of the 10 French tested in Paris, two were tested on French sentences only, because they were participating in another English language study in the laboratory (in total, 24 French were tested on French). They are not included in comparison analyses, but only in the L1 results for the French group. Furthermore, 8 French subjects were tested on American English sentences only, because they were also participating in another study. They are again not included in "within-subject" comparison analyses. In total, 30 French subjects were tested on American. All 22 French subjects tested in the U.S. were tested on both languages.

Participant's biographical data include length of residence in L2 speaking country, amount of interaction in L2 for different situations, the importance of L2 in life, and age of acquisition of L2. Table 2 summarizes for both groups the mean values of each factor.

Table 2. Summary of main biographical characteristics for American and French participants.

	N	Mean age	*sd.*	Age of 1st expo. to L2	*sd.*	Length of residence (yrs)	*sd.*	Inter-action in L2 (%)	*sd.*	Impor-tance of L2 in life (%)	*sd.*
French	32	26.1	6.4	9.7	3.7	3.8	5	48%	0.3	28%	0.17
American	26	28.9	11.0	12.5	4.4	3.7	7	34%	0.3	28%	0.18
difference		F(1,56)=1.19 *p*>.1		F(1,56)=2.56, *p*<.01		F(1,56)=0.19, *p*>.8		F(1,56)=-1.5, *p*>.1		F(1,56)=-0.01, *p*>.9	

3.1.3. Proficiency measure

We are interested in assessing some sort of phonological proficiency, which is possibly related to the amount of L2-native input. Indeed, perceptual learning of this kind of phonological competence could reasonably be initiated through repeated exposure to occurrences of assimilation, that is, through intensive exposure to L2-native input. This factor, it seems to us, is likely to play a far more important role for learning of phonological competence than explicit instruction in L2 could ever play.

As an objective measure of proficiency (rather than the subjective self rating used in both experiments with British English), we thus used the Length of Residence in the L2 country (LoR), in months. We separated both groups in long LoR vs. short LoR on the basis of an arbitrary threshold: For Americans, long LoR is more than 24 months residence in France, short LoR being less than 24 months. For French, due to numerical balance reasons, long LoR was longer than 36 months and short LoR was less than 36 months as a resident in the United States. Table 3 shows the mean LoR values for the different groups. No significant difference can be seen between both populations (American vs. French) within the same LoR-range, indicating that the different separation threshold (24 vs. 36 months) is not confounding.

Table 3. Difference between both groups for comparable Length of Residence

Mean	Long LoR	range	N	Short LoR	range	N
Americans (> 24 months)	116.3	30-396	9	6.7	0-22	17
French (> 36 months)	106.6	48-180	10	11.3	0-36	22
Difference	n.s.			n.s.		

Correlation analyses show that neither country of residence nor participant’s age correlated to the length of residence. In contrast, both the amount of interaction in L2 and the global importance of L2 in life did correlate to the LoR. Thus if high L2 proficiency is induced by intensive interaction in L2 in daily life, using LoR as a measure of proficiency seems to be appropriate. This separation of both groups resulted in the labels “highly proficient” or “advanced learners” for a long LoR, and “less proficient” or “beginning learners” for a short LoR. The label “less proficient”, however, should not be misleading – all participants were very good at speaking and understanding L2, and could perfectly understand every L2 sentence presented in the experiments.

In the following section, results are presented first for L1 in both groups, then for L2, split according to proficiency. The results of Americans hearing American English sentences (subsection 1) are those reported in Experiment 2 of the Darcy et al. study.

3.2. Results (1): Americans hearing American English

Due to space limitations, we will summarize here only the most crucial results. Four items were rejected, and no participant was excluded from the analyses. As in previous experiments, we calculated the compensation index for each participant and each contrast (mean index is 20% for voicing and 43% for place), and used it as a dependent variable in an ANOVA first by participants, then by items. We declared Contrast as a within-subject (respectively between-item) factor (place vs. voicing). We found a significant effect of Contrast by participants, not by items (see discussion below), confirming that all subjects behave similarly and compensate significantly more for place than voicing assimilation ($F_1[1,25]=57$, $p<.0001$; $F_2[1,26]=2.7$, $p>.1$) when hearing American English. Compensation indices are displayed in Fig. 2. The results on American English sentences for the whole group of American listeners is displayed in the left part of the graph.

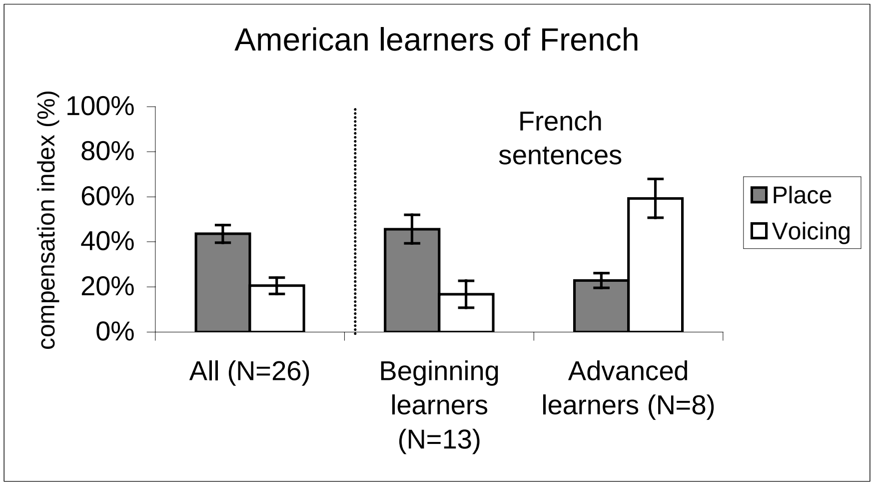

Figure 2. Compensation indices (%) for the group of American listeners, hearing American English sentences (N=26) and French sentences (beginning learners, N=13, and advanced learners, N=8).

This group presents a pattern of results similar to that of French and British native listeners (Darcy, 2006; Darcy et al. to appear). Crucially, the degree of compensation by subjects is higher for a place assimilation process than for the non-native voicing assimilation occurrences. The lack of significant effects for items can be explained by the fact that some items did elicit more compensation than others. Crucially, items in the voicing set were behaving differently depending on their status as a "voicing" or "devoicing" item. Indeed, devoicing items (*big* in *bi[kf]ountain*) were largely compensated, whereas voicing items (*flat* in *fla[dd]am*) were not. This could reflect compensation for a process of partial phonetic final devoicing applying in American English (Hyman 1975; Keating 1984: 293). Therefore, for Americans, only the *voicing* items are really non-native. When restricting the analysis to those items, the difference between indices for place and voicing (without *devoicing* items) is very significant by subjects and by items ($F_1[1,25]=34.5$, $p<.0001$; $F_2[1,19]=8.8$, $p<.008$).

The results for this group serve as a comparison basis for evaluating the performance of the same subjects hearing French sentences, presented in subsection 3 below. We now consider the results of the second French group hearing French.

3.3. Results (2): French hearing French

Error rate checks led to the exclusion of one voicing item. Of 24 tested participants, one was excluded. The mean compensation index is 32% for the place type of change, and 70% for the voicing contrast. Although compensation is not null for a non-native kind of change (32% for place), it is significantly less important than for the native process ($F_1[1,22]=32.9$, $p<.0001$; $F_2[1,29]=18.8$, $p<.0001$).

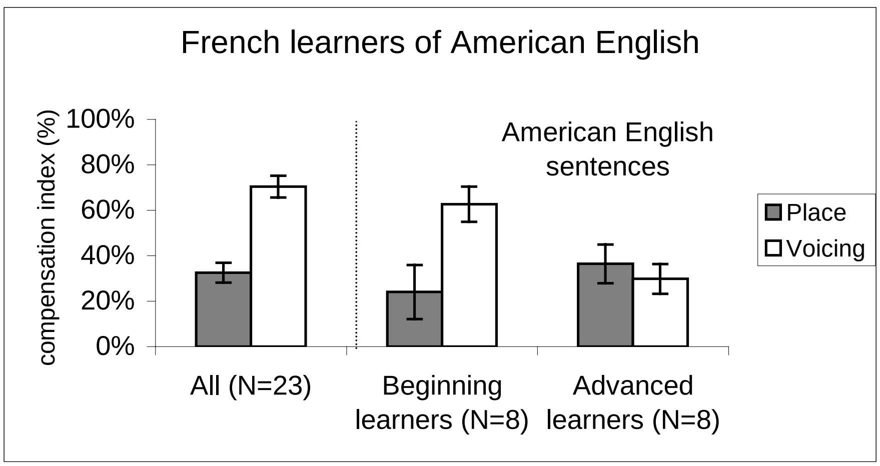

Figure 3. Compensation indices (%) for the group of French listeners, hearing French sentences (N=23) and American English sentences (beginning learners, N=8, and advanced learners, N=8).

Fig. 3 displays the compensation indices for this French group on both French sentences and American English sentences. Compensation indices for French sentences are displayed in the left part of the graph. This pattern of results replicates the previously obtained results with same sentences but another French group and a slightly different procedure reported in Darcy et al. Another difference to the first group tested is that in the present case, these French listeners are also late learners of English. However, this shouldn't radically influence their processing of French if there are two systems. Furthermore, the present results are similar to the pattern obtained for the American group hearing American English: both groups compensate more for a native process than for a non-native one, although there is trace of compensation for the non-native type of change. We turn now to the L2 part of this study, presenting the results of American listeners hearing the French sentences (subsection 3) and of the French listeners hearing the American English sentences (subsection 4).

3.4. Results (3): Americans hearing French

The same item that had been excluded for the English highly proficient group on French sentences was dropped here. According to the participant exclusion criterion mentioned above, four subjects from the beginner group had to be discarded (N=13) as well as one subject from the advanced group (N=8). Compensation indices for both beginners and advanced learners are displayed in the right part of Fig. 2 above. The beginners have a mean compensation index for place of 45%, and of 16% for the voicing contrast, a significant difference by subjects and marginal by items ($F_1[1,12]=8.8$, $p<.012$; $F_2[1,29]=3.0$, $p>.05$). This difference indicates that beginning learners of French, when hearing French, do compensate more often for a place assimilation than for the French-native process, voicing assimilation. For the advanced group in contrast, the index for place is 22%, and 59% for voicing. The difference is significant by subjects and items ($F_1[1,7]=15.2$, $p<.006$; $F_2[1,29]=15.8$, $p<.0001$). Hence they behave like the French native speakers, and similarly to the advanced learners tested in experiment 1.

Unlike in experiment 1, we could conduct a direct comparison of the behavior of the participants in French and in American English. We compared only those subjects who participated successfully in both experiments, thus removing from these analyses (i.e., from the complete American group also) those 5 subjects who have been excluded here. A by-subject ANOVA on indices, restricted to each proficiency level, shows a significant interaction between contrast and test language only for the advanced group ($F_1[1,14]=30.1$, $p<.0001$), but not for the beginner group ($F_1[1,24]=0.5$, $p>.4$). This confirms that beginners display the same pattern for French as for American English, whereas advanced learners changed their behavior in French as compared to American English. As appears from both studies involving beginners so far, the phonology of the native language seems to count more than the phonology of the sentences. By contrast, more advanced learners did show evidence of having adopted at least in part the phonology of the non-native language when they listen to sentences in that language.

We then compare both groups on L1, in order to see if L2 proficiency influences the processing of L1. We performed a by-subject ANOVA on indices in L1 (American English) declaring a new factor: “proficiency in L2”, as well as Contrast. While contrast did show a main effect ($F_1[1,19]=47.0$, $p<.0001$), there was no effect of proficiency ($F_1[1,19]=1.4$, $p>.2$) and no interaction with the other factor ($F_1[1,19]=0.01$, $p>.8$). This means that globally, proficiency in L2 does not affect the pattern of results obtained for L1, but is in fact responsible for the different behavior observed in L2 seen in Fig. 2. We now turn to the results for French listeners hearing American English.

3.5. Results (4): French hearing American English

The same four items that had been excluded for the American group (subsection 1) were also removed here. According to the participant exclusion criterion, 14 subjects did not reach inclusion, leaving for analysis a group of 16 subjects, eight beginners and eight advanced learners. Compensation indices for beginners and advanced learners are shown in the right part of Fig. 3 above. Beginners have a compensation index of 24% for the place contrast, and of 62% for the voicing contrast. This difference is significant by subjects, marginal by items ($F_1[1,7]=6.1$, $p<.05$; $F_2[1,26]=3.7$, $p=0.06$). As we previously observed in the other beginner groups, compensation in L2 is higher for the L1 process than for the L2 one. The advanced learner group obtained a compensation index of 36% for the place contrast and of 29% for voicing, but this difference failed to reach significance ($F_1[1,7]=0.6$, $p>.4$; $F_2[1,26]=0.5$, $p>.4$). Nevertheless, this pattern is different from that of the beginners: an ANOVA on indices for both groups declaring the factors Proficiency (beginner vs. advanced) and Contrast (place vs. voicing) found no main effect of type (marginal only by subjects, p>.05, p>.3), and no main effect of proficiency (p>.2, p>.8), but the significant interaction between both factors ($F_1[1,14]=6.5$, $p<.03$; $F_2[1,26]=5.4$, $p<.03$) reveals that proficiency does play a role in a differential compensation as a function of contrast. Restricting this analysis to one contrast type (first place then voicing) allows us to assess whether proficiency modifies the compensation for both types of contrast equally. No difference between beginners and advanced learners is visible on the place contrast (24% vs. 36% respectively, $F_1[1,14]=0.8$, $p>.3$; $F_2[1,12]=2.2$, $p>.1$). However, compensation on the voicing contrast seems to be more affected by proficiency, as the difference on indices for voicing is significant between beginners (62%) and advanced learners (29%) ($F_1[1,14]=8.1$, $p<.013$; $F_2[1,14]=3.3$, $p>.05$), although marginally by item.

Next, we compare the performance of the same subjects on L1 and L2. We included in these comparisons only those subjects who were tested on both languages, removing those 14 subjects from the French results who had been excluded on American English and removing 1 subject from the beginner group who had been excluded on French, leaving a total of 15 subjects. By-subject ANOVAs show for the advanced group only a significant interaction between contrast and test language ($F_1[1,14]=8.0$, $p=.013$), not for the beginner group ($F_1[1,12]=1.6$, $p>.2$). This confirms that beginners display the same pattern for American English as for French, whereas advanced learners changed their behavior in American English as compared to French, even though they did not completely switch their compensation behavior. However, the significant interaction between both factors confirms that for these French advanced learners also, test language influences the compensation pattern for place vs. voicing.

We finally compare beginners and advanced on L1, in order to see if L2 proficiency influences the processing of L1. We performed a by-subject ANOVA on indices in L1 (French) declaring the factor “Proficiency in L2”, as well as Contrast. While Contrast did show a main effect ($F_1[1,13]=30.0$, $p<.0001$), there was no effect of proficiency ($F_1[1,13]=1.4$, $p>.2$) and no interaction with the other factor ($F_1[1,13]=0.5$, $p>.4$). This means that globally, proficiency in L2 does not affect the pattern of results obtained for L1.

4. General Discussion

Previous work has shown that perceptual compensation for phonological assimilation is driven by language-specific phonological knowledge (Darcy et al, to appear, Koster 1987; Otake et al. 1996; Beddor and Krakow 1999). In this study, we explored compensation for assimilation in late learners of a second language, as a function of amount of exposure to the second language. The method and stimuli we used allowed us to compare the processing of an assimilation pattern that exists only in the native language, with one that exists only in the non-native language. We thus obtained a measure of the extent to which subjects listening to their second language were using the pattern of compensation appropriate to that L2, or were using instead the compensation appropriate to their native language.

Results of Experiment 1 with British English late learners of French show that although beginning learners inappropriately apply the compensation of their L1 to their L2, advanced learners have almost completely acquired the compensatory processes of the L2. Experiment 2 used a fully crossed design with American English learners of French and French learners of American English. Both populations were tested in the two languages. Both groups applied the compensation pattern of their L1 onto L2 if they were beginning learners (mean exposure less than 1 year). However, more advanced learners started to significantly shift their pattern of compensation towards that of the L2. That is, American learners of French compensated more for voicing than for place assimilations (just like the native French did). Vice versa, the French learners of English dropped their compensation for voicing, although their compensation for place did not reach the pattern of the native American English speakers. Interestingly, all late learners continued to apply the appropriate pattern of assimilation when they were hearing their own native language.

One might argue that the differences we found between beginners and advanced learners are due to a difference in vocabulary size. Indeed, knowing that “rop” is not a real French word might induce advanced participants to interpret it more readily as the target "robe" than beginners, who might be uncertain whether "rop" is a different word. However, such a lexical bias would apply equally for place and voicing items, and irrespective of the appropriate versus inappropriate context. In other words, given our design, lexical knowledge can only create a pattern of error rate, not a change in the compensation index. In fact, Darcy (2006) found similar patterns of compensation for real words like "robe" and non-words like "nobe", showing that lexical knowledge is clearly not involved here.

In brief, the combined results of these experiments suggest that within a few years of exposure to a second language, learners can build a separate system for the processes of L2, without modifying the L1 system, and are able to switch from one to the other depending on the language they are hearing. This conclusion contrasts with several claims that have been made regarding the plasticity of language-specific perceptual processes.

First, our findings contrast with claims of strong limits in the plasticity of perceptual processing. Research in perception of non-native contrast has shown that some non-native contrasts may be very difficult to perceive, and that even after extensive training, such contrasts remain processed in a non-native way (Hallé, Best, and Levitt 1999; Iverson et al. 2003; see also Lively, Pisoni, and Logan 1992). Pallier, Bosch and Sebastián-Gallés (1997), Dupoux et al. (submitted) go further and claim that under naturalistic exposure conditions, a second language basically does not alter the way in which speech sounds are parsed onto native phonetic categories. Flege (1995; Flege, Bohn, and Jang 1997) has a less extreme position, and proposes that there is some plasticity allowing bilinguals to shift native category boundaries as a function of L2 usage (see also Norris, McQueen, and Cutler 2003). Yet, these changes are small compared to the ones we reported. Notice however the difference: in our study, we tested French and English with stimuli using phonemic categories that exist in both languages. We did not test how phonetic differences between the realization of voiced and voiceless stops may be perceived across the two languages; rather, we looked at what kind of compensatory mechanisms may exist when a lexical form is changed by a contextual process. This suggests that parsing continuous speech into phonetic categories on the one hand, and matching phonetic surface forms onto underlying lexical forms on the other, are performed by different computational systems, with different potentials for modification by linguistic experience.[6]

Second, our findings contrast with claims that there can only be one phonological system, and that any potential acquisition is bound to modify the processing of the L1 as well as of the L2. For instance, Flege (1995) proposes that speech categories are flexible but common to L1 and L2. Similarly, Cutler et al. (1992) proposed that even native bilinguals cannot entertain two phonological systems at once, and that they apply only one perceptual strategy. Peperkamp, Dupoux, and Sebastian-Gallés (1999) found that more than 30% of the native French-Spanish bilinguals from mixed families display the 'stress deafness' effect typical of French monolinguals. This suggests that even massive exposure to two languages from birth is not sufficient to ensure that the two languages will be processed in a native-like fashion. Here, instead, we found that participants can acquire a secondary system of phonological compensation rather smoothly without loosing the system applying in their native language. How do we account for this discrepancy? We could appeal to the same line of reasoning as the one proposed above, namely that the studies reporting evidence in favor of a single phonological system all dealt with perception or production of phonetic categories, whereas we consider a rule system that presumably deals with sounds that have already been categorized and focuses on the mapping of phonetic forms onto the lexicon. It is possible that such a mechanism is quite distinct from the one that performs categorization, in that it is much more plastic, and allows for the acquisition and use of multiple phonological systems (likewise, later processing stages may use separate cortical structures compared to earlier ones; see Marian, Spivey, and Hirsch 2003).

In fact, there are independent reasons to propose that the mapping between surface and underlying forms requires a system that is both plastic and allows for multiple instantiations. Indeed, most often, we hear words that are phonetically distorted compared to the standard form. Such distortions can come from regional accent, idiolects, foreign accents, or distortions induced by telephonic equipments. Yet, we seem to adapt rather quickly to such distortions. Greenspan, Nusbaum, and Pisoni (1988) have shown that participants can learn to adapt to synthetic speech, and that such learning transfers to novel words or sentences. Similarly, Dupoux, and

Green (1997) have shown that participants can quickly adapt to artificially time-compressed speech, and that such adaptation transfers to novel words and speakers. In order to account for these results, it is necessary to postulate a system that specifies how abstract word forms can be matched to a speech signal that departs in significant ways from what would be the normal pattern. In other words, we could propose, as a speculation, that the system that allows phonological compensation for assimilation is also the system that allows one to learn and compensate for specific patterns of pronunciation distortions, as they occur in synthetic speech, or dialectal variants of one's native language. Further research is needed to explore this hypothesis in more detail.

Before closing, we would like to comment briefly on two minor aspects of our results. First, we observed that all groups did show a limited compensation for the non-native process respectively, even though it is less than for the native process. This suggests the existence of a language independent mechanism of contextual contrast sensitivity, like that proposed by David Gow with the Feature Parsing mechanism (Gow 2003), and which would apply *in addition* to the language-specific compensation mechanism (see Darcy et al., to appear, for further discussion).

Second, we uncovered an unexpected asymmetry between French learners of English and American learners of French. The progressive differentiation of the L2 system for French was not as complete as for American advanced learners. French learners seem to have more difficulties in acquiring the non-native process; indeed, they mostly inhibited compensation for voicing assimilation when hearing English, but did not increase their compensation for place to the extent that native English listeners did. Perhaps one reason is that the French learners of English were less advanced than the American or the British learners of French. Such an asymmetry was not apparent in the biographical data, though, but could reflect the fact that English phonology – containing more segments, contrastive stress, as well as a great deal of positional allophony – is more complex than French phonology. As a result, French listeners would be delayed in their acquisition of English. Another possibility is that voicing and place assimilation differ in the first place. There is phonetic evidence that French voicing assimilation is more categorical than English place assimilation (Féry 2003; Nolan 1992; Rigault 1967). This is apparent in the data of the French hearing French and American English hearing American English. The French process seems to be compensated for more completely than the English one. Our stimuli with deliberate substitutions are then perhaps closer to real French voicing assimilation than to English place assimilation. This could explain the lower compensation for place assimilation among both English and French listeners. Similarly, because of such a difference between the French and English assimilation processes in natural speech, French learners of English have less clear evidence for the existence of place assimilation. A third possibility could be that, similarly to phonetic categories, it may be easier to adjust the weighting of assimilations that already occur even to a small extent in the L1 (as partial phonetic devoicing), than to establish a phonological category or process that does not exist at all in the L1. In this case, it would be harder for French to acquire place, because they have no familiarity at all with alternations modifying the place feature, whereas Americans would already have some sort of familiarity with variation along the voicing feature, due to the presence of this partial phonetic devoicing process. [7]

To recapitulate, our main conclusion is that as far as compensation for assimilation is concerned, it is possible for the same person to have two distinct coexisting phonological systems and to switch from one to the other as a function of the heard language. This suggests that compensation requires mechanisms different from those involved in phonetic categorization. More research is needed to determine the nature of these mechanisms.

Notes

1. Several studies have documented that spontaneous realizations of assimilation are most of the time gradient, and cannot be described as a simple phoneme substitution (Nolan 1992; Ellis and Hardcastle 2002). However, the fact that speech production is gradient does not imply that speech perception is also gradient. On the contrary, perception is notoriously categorical (Harnad 1987): hearers have great difficulties in accessing fine-grained phonetic cues, unless

these cues yield a change in phoneme category. The issue, therefore, is not so much whether assimilation is gradient or discrete, but rather, how often assimilated tokens cross a perceptual category boundary. If even a small proportion of assimilated tokens happen to cross a perceptual boundary, this creates a compensation problem no different from the one that would have been created by the presence of discrete deliberate substitutions. Nolan (1992) found that despite differences in phonetic detail, English hearers compensate for naturally produced place assimilation to the same extent as they do for deliberate substitutions. More generally, several studies have shown that the perceptual apparatus displays robust and numerically large compensation for deliberate substitutions, even in cases where the underlying process in production has been claimed to be gradient (Gaskell and Marslen-Wilson 1996, 1998, 2001).

2. Because of word order differences in French vs. English, targets are nouns in French and prenominal adjectives in English. Context words are postnominal adjectives for French and nouns for English.
3. Average frequency of American English target words is 151 for voicing and 156 for place, t(15)=0.06. $p>.1$.
4. This sentence is pronounced as [*ɛlamisaʀɔpsal*].
5. No main effect of proficiency ($p>.5$; $p>.9$) nor of contrast type ($p>.7$; $p>.4$) became visible, because both groups behave in opposite ways such that effects cancel each other out.
6. Error rate analyses in our data show consistently more errors on L2 but no effect of proficiency, suggesting that categorization is still more difficult in L2, and less subject to improvement with more exposure.
7. We are grateful to an anonymous reviewer for pointing this out.

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Appendix

Detection rates (%) in each condition as a function of the type of contrast (place vs. voicing) with indices for each group.

	Place				Voicing			
Exp. 1	V	U	NC	*P-index*	V	U	NC	*V-Index*
E – E	60	46	89	*35*	25	20	92	*6*
E (low) – F	58	33	82	*55*	53	38	87	*30*
E (high) – F	32	12	84	*28*	70	36	88	*65*
Exp. 2								
A – A	46	11	94	*43*	33	18	91	*20*
A (low) – F	49	24	84	*45*	32	22	84	*16*
A (high) – F	25	6	87	*22*	61	26	86	*59*
F – F	40	17	91	*32*	69	20	92	*70*
F (low) – A	37	19	87	*24*	64	31	87	*62*
F (high) – A	45	23	86	*36*	54	37	92	*29*

Key to abbreviations

Conditions:	viable (V), unviable (U), no-change (NC)
E – E	English subjects hearing English sentences, n = 27
E (low) – F	English subjects (low) hearing French sentences, n = 23
E (high) – F	English subjects (high) hearing French sentences, n = 14
A – A	American subjects hearing American sentences, n = 26
A (low) – F	American subjects (low) hearing French sentences, n = 13
A (high) – F	American subjects (high) hearing French sentences, n = 8
F – F	French subjects hearing French sentences (n=23)
F (low) – A	French subjects (low) hearing American sentences (n=8)
F (high) – A	French subjects (high) hearing American sentences (n=8)