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Adaptation to Novel Accents: Feature-Based Learning of Context-Sensitive Phonological Regularities

Katrin Skoruppa,[a] Sharon Peperkamp[b]

[a]*Department of Speech, Hearing and Phonetic Sciences, UCL Division of Psychology and Language Sciences*
[b]*Laboratoire de Sciences Cognitives et Psycholinguistique (EHESS – DEC-ENS – CNRS)*

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Abstract

This paper examines whether adults can adapt to novel accents of their native language that contain unfamiliar context-dependent phonological alternations. In two experiments, French participants listen to short stories read in accented speech. Their knowledge of the accents is then tested in a forced-choice identification task. In Experiment 1, two groups of listeners are exposed to newly created French accents in which certain vowels harmonize or disharmonize, respectively, to the rounding of the preceding vowel. Despite the cross-linguistic predominance of vowel harmony over disharmony, the two groups adapt equally well to both accents, suggesting that this typological difference is not reflected in perceptual learning. Experiment 2 further explores the mechanism underlying this type of phonological learning. Participants are exposed to an accent in which some vowels harmonize and others disharmonize, yielding an increased featural complexity. They adapt less well to this regularity, showing that adaptation to novel accents involves feature-based inferences.

Keywords: Speech perception; Phonological learning; Dialects; Accents; Features

1. Introduction

While it has long been assumed that adults' phonological systems are stable, recent work suggests that even short exposure to novel sound patterns can alter listeners' representations (Clarke & Garrett, 2004; Kraljic & Samuel, 2005, 2006, 2007; Maye, Aslin, & Tanenhaus, 2008; Norris, McQueen, & Cutler, 2003). This flexible adaptation to novel sound structures is useful in daily life for coping with unfamiliar dialects and foreign accents. For example, Clarke and Garrett (2004) report that initially increased reaction times for foreign-accent

Correspondence should be sent to Katrin Skoruppa, Chandler House, University College London, 2 Wakefield Street, London, WC1N 1PF, UK. E-mail: k.skoruppa@ucl.ac.uk

words approach values for native words after only 1 min of exposure to foreign-accent sentences (but see Floccia, Goslin, Girard, & Konopczynski, 2006). However, the constraints on this flexibility remain uncertain, as these two studies did not control for the particular sound changes introduced by the accent or dialect, making it difficult to infer to which changes listeners can adapt and to which ones they cannot.

More controlled studies on phonological learning suggest that adaptation can affect single sound contrasts as well as sets of sounds. Several recent studies have examined phonetic category shifts after exposure to accented word lists. Norris et al. (2003) exposed Dutch participants to [f]- and [s]-final words in which either [f] or [s] was replaced by a sound that was ambiguous between [f] and [s]. In a subsequent categorization task, participants were more likely to categorize this ambiguous sound as [s] if it had replaced [s] during exposure, and as [f] if it had replaced [f]. A similar study with American listeners, involving sounds that were ambiguous between [s] and [ʃ], also reported a robust category shift, which was still present 25 min after exposure (Kraljic & Samuel, 2005). Likewise, American listeners showed a category shift for sounds that are ambiguous between [d] and [t], and this shift was generalized to sounds that are ambiguous between [b] and [p], which were not used during exposure, as well as to unknown talkers (Kraljic & Samuel, 2006). In an accent-learning setting using more naturalistic stimuli, Maye et al. (2008) exposed American participants to a 20-min-story in which all front vowels were systematically lowered. For example, the verb *live* was pronounced as *lev*. In a subsequent lexical decision task, participants accepted new items with altered front vowels (e.g., *ked*—altered from *kid*) more readily as English words than during a pretest, suggesting that they adapted their phonetic categories to the new accent.

While these studies underline adult listeners' flexibility with respect to phonetic categories, there is another level at which accents can affect sound systems. Indeed, accent variation involves not only across-the-board shifts of phonetic categories but also phonological alternations that apply only in specific contexts. Focusing on dialects of English, we can list numerous examples affecting both consonants and vowels, all described in Wells (1982): The coronal stops [t] and [d] are tapped intervocalically, for instance in the word *butter*, in American English as well as certain other dialects. Voiceless fricatives such as [f] are voiced (i.e., [v]) if they appear in word-initial position in certain dialects spoken in West England. In Caribbean English, word-final [t] and [d] are deleted if they are preceded by another consonant. The vowel [æ] is raised to [ɛ] before [r] in many American dialects, and diphthongs are raised as well before voiceless consonants in some American and Canadian dialects. Finally, in dialects in the London area as well as in some regions in America, a vowel and a following nasal consonant are coalesced into a nasalized vowel.

Little research has been dedicated to the question of how listeners adapt to unfamiliar context-dependent phonological regularities. To our knowledge, only two studies have investigated the perception of context-sensitive alternations in unfamiliar dialects. First, a priming study by Sumner and Samuel (2009) suggests that Americans who have never lived in New York find it difficult to process English *r*-final words (e.g., *baker*) pronounced in the New York dialect, in which word-final [r] is deleted. By contrast, listeners who were raised in New York had less difficulty understanding *r*-less variants, even if they did not speak the

New York dialect themselves and thus did not produce *r*-less words. Second, a study by Scott and Cutler (1984) on the processing of American tapping shows that listeners can adapt to context-dependent regularities in nonnative dialects with several years of exposure: British English speakers who had lived in the United States for an average duration of 4 years had less processing difficulties with tapped words such as *butter* than British English speakers who had never lived in the United States. However, they still performed worse than American English speakers, suggesting that some processing difficulties for nonnative alternations remain.

Adaptation to novel context-dependent alternations has also been studied by means of artificial language learning experiments. Using a forced-choice identification task, Pycha, Nowak, Shin, and Shosted (2003) showed that listeners can learn front/back vowel harmony, by which vowels in adjacent syllables agree on the front/back dimension (e.g., front vowel + front vowel [mitɛk], or back vowel + back vowel [sunʌk]), from short exposure. Using a similar design, Finley and Badecker (2009) confirmed that listeners can learn front/back harmony and found that they can also learn height harmony. Moreton (2008) likewise reports that listeners can learn height harmony, as well as a height-voice pattern, in which the height of a vowel depends on the voicing feature of the following consonant. Finally, using a production task, Wilson (2006) showed that participants can learn velar palatalization, by which velar stops become palatal before front vowels, from short exposure.

Artificial language learning studies have the drawback that learning can be quite explicit, for two reasons. First, the exposure typically contains few lexical items, most often without semantic content, which makes the alternations stand out rather saliently. Second, they often involve extensive training, sometimes with corrective feedback, such that it cannot be excluded that participants rely on their general problem-solving abilities rather than on more implicit phonological learning skills. An explicit laboratory learning situation is, then, quite different from real-life dialect adaptation. The present study therefore examines adaptation to novel phonological alternations in as naturalistic a setting as possible. Our paradigm is adapted from that of Maye et al. (2008), in that participants are exposed to stories in a newly created accent of their native language. The accent, however, is characterized by additional context-dependent alternations, very similar to the ones in Pycha et al. (2003), rather than by an across-the-board shift in phonetic categories as investigated by Maye et al. (2008). We use a forced-choice identification task (instead of lexical decision in Maye et al.) to test whether participants can identify items that are pronounced with the accent they were exposed to. As Maye et al., we test participants' performance both on items that occurred during exposure, for which correct responses can be achieved either by remembering them from the stories or by applying the newly learned regularity, and on novel items, for which correct responses necessarily involve the extraction of the regularity during exposure and its generalization across the lexicon.

Experiment 1 shows that French listeners can learn novel phonological regularities from short exposure to accented speech, and that adaptation takes place at an abstract, phonological, level. That is, during the test phase, participants show adaptation to the novel accents not only for words they were exposed to but also for novel words. Moreover, we examine whether they can learn different types of phonological alternations. In particular, following

Pycha et al. (2003), we compare the acquisition of vowel harmony and vowel disharmony. Cross-linguistically, vowel harmony is very common (van der Hulst & van de Weijer, 1995), whereas vowel disharmony is extremely uncommon.[1] The preponderance of vowel harmony is arguably due to the fact that harmonic words are easier to articulate than disharmonic words. In some theories, ease of articulation is synchronically translated into an abstract learning bias in the speaker's mind that facilitates the acquisition of harmony over disharmony (e.g., Archangeli & Pulleyblank, 1994; Donegan & Stampe, 1979; Hayes & Steriade, 2004). Other theories do not presuppose any synchronic learning biases, but they explain the preponderance of certain phonological patterns diachronically (e.g., Ohala, 1993; Bybee, 2001; Blevins, 2004; for an overview, see Hansson, 2008). In this context vowel harmony has been argued to arise out of universal vowel-to-vowel coarticulation. That is, due to strong coarticulation, speakers' intended disharmonic sequences are often ambiguous between harmonic and disharmonic and listeners can sometimes perceive them as harmonic, a process that can lead to the creation of a new harmony alternation (Blevins, 2004). Disharmony, by contrast, does not arise easily, because there are no co-articulation effects that make harmonic sequences become closer to disharmonic ones. As a consequence, vowel disharmony is less likely to be introduced into a language than vowel harmony.

Both theories explain why harmony is more common than disharmony, but only the former predicts that harmony is learned better and/or faster than disharmony. In the explicit study by Pycha et al. (2003) participants learned the vowel harmony alternation described above (i.e., front vowel + front vowel [mitɛk], or back vowel + back vowel [sunʌk]) and a corresponding disharmony alternation (i.e., back vowel + front vowel [sunɛk], front vowel + back vowel [mitʌk]) equally well; we test whether this is also the case in a more naturalistic setting.

Experiment 2 further explores the mechanisms that underlie this type of phonological learning. Cross-linguistically, both the targets of phonological regularities and their triggers (i.e., the context in which they apply) often concern sets of sounds that are homogeneous with respect to one or more phonological features. For instance, recall from above the English dialectal process by which [t] and [d] are tapped intervocalically. The targets [t] and [d] are both *coronal, oral,* and *non-continuant*, while the contexts are *vocalic*. Whether listeners use such feature-based representations to group sounds and sound alternations together when adapting to new accents is largely an open question.

Artificial language-learning studies show that features play a role in phonological learning: Pycha et al. (2003) found that successful learning of a vowel harmony and a vowel disharmony alternation contrasts with failure to learn a featurally more complex mixture of the two, in which the type of alternation depends on the identity of the preceding vowel (harmony after [i, æ, u, a], disharmony after [ɪ, ʊ]). Further studies report generalization of newly learned alternations across natural classes, that is, sets of segments that share one or more features: Finley and Badecker (2009) found that participants generalized a newly learned vowel harmony alternation from a limited set of exposure vowels (e.g., [i ↔ u] and [æ ↔ a]) to novel vowels (e.g., [e ↔ o]) that did not appear during the exposure phase, but shared features with the exposure vowels. With a production task, Wilson (2006) obtained generalization of a newly learned alternation (here, velar palatalization) to novel context vowels. Finally, features are also important for phonotactic learning. In particular, Endress and Mehler (2010) found that phonotactic constraints on word-medial consonant sequences were only learned from brief exposure if they concern featurally similar sounds. Similarly, Kuo (2009) reports that listeners only learned new phonotactic constraints on onset clusters if the consonants involved shared a phonological feature.

Hence, there is now ample evidence for feature-based learning in the acquisition of artificial languages. Here, we address the same question of the role of feature-based representations in the realm of adaptation to unfamiliar accents, using a more naturalistic learning paradigm. Experiment 2 tests whether participants can learn a new accent containing a featurally complex mixture of vowel harmony and disharmony similar to the one in Pycha et al. (2003).

2. Experiment 1

This experiment investigates whether French listeners show rapid adaptation to newly created accents that contain novel context-sensitive alternations. We define two novel French accents that we call Harmonic French and Disharmonic French. Both are derived from Standard French by applying one additional phonological regularity, the former by applying a vowel harmony alternation, the latter by applying a vowel *dis*harmony alternation. Fig. 1 shows the vowel pairs that alternate in the novel accents. Note that the same sound changes—changes concerning rounding of the front vowels [i ↔ y, e ↔ ϕ, ɛ ↔ œ] —apply in both accents, but in different contexts.

The novel alternations apply in words that contain two non-low front vowels in adjacent syllables. They are progressive: The rounding value of the first vowel determines the one of the second vowel. In Harmonic French, front vowels *agree* in rounding. For instance, the word *liqueur* (liquor), which is pronounced [likœʁ] in Standard French, becomes *liquère* [likɛʁ]; the rounded vowel [œ] becomes unrounded [ɛ] due to the presence of unrounded [i] in the preceding syllable. Vice versa, in *naturel* (natural), pronounced [natyʁɛl] in Standard French, [ɛ] becomes [œ] due to the presence of rounded [y] in the preceding syllable, yielding *natureul* [natyʁœ1].

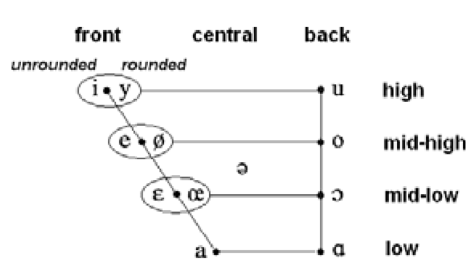

Fig. 1. French oral vowels. Alternating vowel pairs are shown in ellipses.

Table 1
Sample harmonic and disharmonic French words as realized in Harmonic and Disharmonic French in Experiment 1

Standard French	Harmonic French	Disharmonic French
Harmonic		
pudeur	pudeur	**pudère**
ordinaire	ordinaire	**ordineure**
Disharmonic		
liqueur	**liquère**	liqueur
naturel	**natureul**	naturel

Note. Modified words are shown in boldface.

In Disharmonic French, the same changes apply in the opposite context, that is, two consecutive non-low front vowels *disagree* with respect to their rounding values. For instance, the word *pudeur* (prudity), which is pronounced [pydœʁ] in Standard French, contains two rounded vowels, [y] and [œ]; the second rounded vowel [œ] becomes unrounded [ε], due to the presence of rounded [y] in the preceding syllable, and the word becomes *pudère* [pydεʁ]. Vice versa, in *ordinaire* (ordinary), pronounced [ɔʁdinεʁ] in Standard French, [ε] becomes [œ] due to the presence of unrounded [i] in the preceding syllable, yielding *ordineure* [ɔʁdinœʁ]. Words like *pudeur* and *naturel*, which are modified in Harmonic French, remain unchanged in Disharmonic French, as they already respect the phonological regularity of this accent: Their non-low front vowels disagree in rounding. Similarly, *pudeur* and *ordinaire* remain unchanged in Harmonic French.

Hence, Harmonic and Disharmonic French are derived from Standard French by the same vowel changes that apply in different contexts. For comparison, sample words and their realizations by accent are shown in Table 1.

Rounding harmony and disharmony exist in none of the French dialects spoken in France,[2] and in none of the commonest foreign accents to which native French speakers are exposed.

2.1. Method

2.1.1. Participants

Sixty monolingual native French speakers participated in the experiment. They were between 18 and 35 years old and had no known history of hearing or language impairment. Each participant was randomly attributed to one of the two accents.

2.1.2. Material

We selected 304 French words of two or more syllables in the database Lexique 3 (New, Pallier, Ferrand, & Matos, 2001) for the exposure phase. Among these, 152 words are disharmonic, that is, they contain two front vowels in adjacent syllables that differ in rounding and that are hence pronounced differently in Harmonic French (e.g., *liqueur* → *liquère*). The remaining 152 ones are harmonic; that is, they contain two front vowels in adjacent syllables that are either both rounded or both unrounded, and they are hence pronounced differently in Disharmonic French (e.g., *pudeur* → *pudère*). All words contain at most two adjacent syllables with front vowels, and they can occur in any position within the word. Among these 304 words, 20 disharmonic ones were matched to 20 harmonic ones of the same grammatical category (for instance, *liqueur* and *pudeur*; for a complete list, see Appendix S1), such that there were no significant differences in spoken word frequency [$t(38) < 1$] and number of phonemes [$t(38) < 1$], syllables [$t(38) < 1$], and morphemes [$t(38) < 1$]; these words were to be used during the test phase too. For the test phase, we selected an additional 40 pairs of similarly matched harmonic and disharmonic French words without significant differences in spoken word frequency [$t(78) < 1$] and number of phonemes [$t(78) < 1$], syllables [$t(78) < 1$], and morphemes [$t(78) < 1$] (see Appendix S2).

We wrote four stories in which the 304 exposure words each occurred at least once (members of matched pairs occurred equally often). Overall, the stories contained 176 tokens of disharmonic words and 176 tokens of harmonic words. A native speaker of French recorded these stories in both Harmonic and Disharmonic French with natural intonation.[3] Hence, in Harmonic French, the disharmonic words were pronounced in their altered, harmonic counterpart, whereas the harmonic words were pronounced as in Standard French; vice versa, in Disharmonic French, the harmonic words were pronounced in their altered, disharmonic counterpart, whereas the disharmonic words were pronounced as in Standard French. For example, compare the Standard French pronunciation of a sentence in (1a) with the Harmonic and Disharmonic versions in (1b) and (1c), respectively (changes are indicated in boldface): In Harmonic French, the disharmonic word *liqueur* is harmonized to *liquère*, whereas in Disharmonic French, the harmonic word *pudeur* is disharmonized to *pudère*.

(1) a. Standard French: *Sans pudeur, il se versa un verre de liqueur.*
'He shamelessly poured himself a glass of liquor.'
b. Harmonic French: *Sans pudeur, il se versa un verre de* ***liquère****.*
c. Disharmonic French: *Sans* ***pudère****, il se versa un verre de liqueur.*

The 60 matched pairs to be used for testing were recorded in isolation by the same speaker with a change in rounding of the second front vowel. The disharmonic ones were thus recorded in the Harmonic French version (e.g., *liquère*, from *liqueur*) and the harmonic ones in the Disharmonic French version (e.g., *pudère*, from *pudeur*). Hence, all test items were nonwords in Standard French. The 60 pairs were divided into two lists, each containing 10 pairs of words that appeared in the stories (exposure items) and 20 pairs of words that did not (novel items).

2.1.3. Procedure

Participants listened to the four stories in either Harmonic or Disharmonic French over headphones. They were instructed to memorize the content of the stories while ignoring the reader's accent. At the end of each story, participants had to answer a multiple-choice question about the content of the story. Then, the same stories were played once more, and participants answered two different multiple choice questions at the end of each one. None of these questions concerned words that were changed in one of the accents, in order to avoid drawing participants' attention toward those words.

During the subsequent test phase, participants heard one list of 30 pairs of test items (e.g., *liquère–pudère*, both nonwords in Standard French) with an ISI of 700 ms. Their task was to indicate which one they thought was pronounced in the accent they had been exposed to, by pressing '1' for the word they heard first or '2' for the second one. If a participant took more than 5 s to answer, she was instructed to respond faster henceforth.

In half of the trials, the harmonized item (e.g., *liquère*, legal in Harmonic French) was presented first, in the others the disharmonized one (e.g., *pudère*, legal in Disharmonic French). For each of the exposure groups, half of the participants were tested on the first list of 30 pairs, the other half on the second one. The order of presentation of the pairs within each list was randomized.

2.2. Results and discussion

Fig. 2 shows boxplots of percentages of correct responses by participant for the two accent groups for exposure and novel items during the test phase. Note that what was considered a correct response differed according to exposure group: For participants exposed to Harmonic French, choosing the harmonized item was evaluated as correct, whereas participants exposed to Disharmonic French had to choose the disharmonized item.

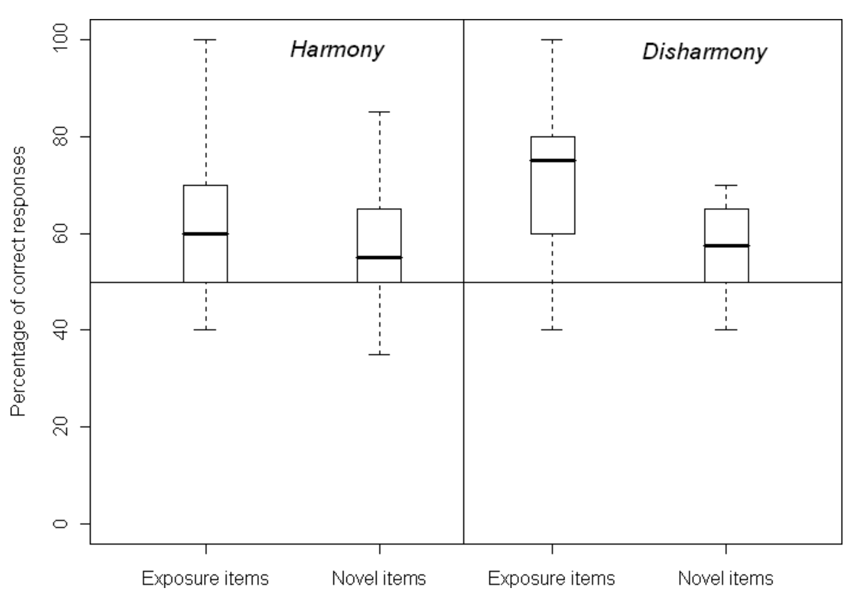

Fig. 2. Boxplot showing the percentages of correct responses for the two exposure groups by item type in Experiment 1. Whiskers indicate minimum and maximum values; the solid line represents chance performance (50%).

Exposure items and novel items were analyzed separately. Following Quené and van den Bergh (2008), the results were analyzed in mixed-effect logistic regression models with random intercepts for participants and random slopes for items. No fixed effects were declared for the initial models. Overall performance was significantly different from chance both for exposure items (estimated coefficient = 0.83, $SE = 0.13$, $z = 6.24$, $p < .001$) and for novel items (estimated coefficient = 0.29447, $SE = 0.06$, $z = 4.90$, $p < .001$), as indexed by the intercept values in both models. These two initial models were compared to models containing the same random effects and an additional fixed effect, Exposure Group (Harmonic French vs. Disharmonic French). The addition of this parameter did not provide a better likelihood fit in a χ^2 test compared to the initial models, neither for the exposure items [$\chi^2(1) = 2.40$, $p = .12$] nor for the novel items [$\chi^2(1) < 0.01$, $p = .96$], suggesting that performance did not differ according to the accent the participants had learned.

Above-chance scores on both exposure and novel items indicate that participants not only successfully memorized accented words from the stories but also adapted to the accent at an abstract, phonological level. Maye et al. (2008) found a phonetic category adaptation effect that similarly generalized to novel, unexposed words. In our study participants additionally learned the relationship between the target vowels, that is, the vowels that were pronounced differently than in Standard French, and the contexts in which they occurred (Harmonic French: Round front vowels after rounded ones, and unrounded front vowels after unrounded ones; Disharmonic French: Round front vowels after unrounded ones, and unrounded ones after rounded ones).

Thus, our results suggest that listeners can adapt to a novel context-dependent regularity within 40 min, even though acquisition remains largely incomplete with such a short exposure. In contrast with other dialect adaptation studies (Kraljic & Samuel, 2005, 2006, 2007; Norris et al., 2003) and artificial language learning studies (Pycha et al., 2003), it can be argued that the learning setting was quite naturalistic and implicit. This is because, first, we used stories rather than word lists, and, second, because during exposure participants were not actively engaged in learning the accent, but rather in memorizing the stories.[4]

The finding that vowel harmony and vowel disharmony were learned to the same extent suggests, moreover, that adult learners do not have a bias favoring harmony over disharmony. This result is in accordance with the artificial language learning study of Pycha et al. (2003), where no difference was observed between the learning of front/back harmony and that of front/back disharmony by English-speaking adults. Pycha et al. used an explicit artificial language learning paradigm and only two target vowels; as a consequence, participants might have relied on conscious, nonlinguistic, learning strategies. The fact that we obtained the same result using a passive listening paradigm and six target vowels is a more robust indicator that harmony and disharmony are equally learnable.

These findings suggest, then, that there are no abstract linguistic biases favoring harmony over disharmony in perceptual phonological learning. Provided young children show the same behavior, the preponderance of vowel harmony in the world's languages must stem from a different source, most likely from phenomena of diachronic sound change or from an ease-of-articulation constraint favoring harmony that affects speech production only.

There is a further question concerning the mechanisms that underlie this type of phonological learning that remains to be answered. So far, we have described the regularities to which participants are exposed in the most economical way, by making reference to the feature *rounding*. Specifically, we described the novel phonological regularities as in (3) and (4).

(3) Harmonic French:
Rounded front vowels occur after rounded front vowels, and unrounded front vowels after unrounded ones.

(4) Disharmonic French:
Rounded front vowels occur after unrounded front vowels, and unrounded front vowels after rounded ones.

This is in accordance with elementary phonological theory, but we do not know whether *learners* make this type of feature-based inferences. A different way in which listeners might learn the regularities of Harmonic and Disharmonic French is stated in (5) and (6), where these are expressed in terms of atomic segments without reference to features.[5]

(5) Harmonic French:
[y,ϕ,œ] occur after any of the vowels [y,ϕ,œ], and [i,e,ε] after any of the vowels [i,e,ε].

(6) Disharmonic French:
[y,ϕ,œ] occur after any of the vowels [i,e,ε], and [i,e,ε] after any of the vowels [y,ϕ,œ].

The next experiment investigates whether listeners make feature-based inferences by exposing participants to a regularity involving the same vowels as before, but that does not allow for a unified feature-based inference like the ones in (3) and (4).

3. Experiment 2

In this experiment, participants are exposed to a third novel accent, Mixed French, in which the high vowels [i] and [y] disharmonize to preceding front vowels, whereas the mid vowels [e], [ϕ], [ε], and [œ] harmonize to it. Without making reference to features, the resulting regularity can be stated as in (7). Note that it is as simple as the regularities in Experiment 1 described in (5) and (6).

(7) Mixed French:
[i,ϕ,œ] occur after any of the vowels [y,ϕ,œ], and [y,e,ε] after any of the vowels [i,e,ε].

However, if reference to features is made, two cases need to be distinguished, as in (8), which makes this description more complex than the feature-based ones in the first experiment described in (3) and (4).

(8) Mixed French:
  a. Rounded *high* front vowels occur after unrounded front vowels, and unrounded *high* front vowels after rounded ones.
  b. Rounded *mid* front vowels occur after rounded front vowels, and unrounded *mid* front vowels after unrounded ones.

If listeners make feature-less inferences (or even treat each alternating sound pair individually, see note 4), their performance should be as good as in the previous experiment. By contrast, if they make feature-based inferences it should be worse; indeed, from a featural viewpoint Mixed French is more complex, in that its alternation requires two distinct feature-based inferences rather than a single one.

3.1. Method

3.1.1. Participants

Thirty monolingual native French speakers participated in the experiment. They were between 18 and 35 years old and had no known history of hearing or language impairment. None of them had participated in the previous experiment.

3.1.2. Material

The test items and stories were the same as before. For exposure, the stories containing 176 harmonic and 176 disharmonic words were recorded in Mixed French by the same speaker and during the same recording session as the Harmonic and Disharmonic French versions used in Experiment 1. As in Experiment 1, a total of 176 words in the stories were produced with a vowel change. Indeed, among the exposure items, the target front vowel was high ([i] or [y]) in half of the harmonic and in half of the disharmonic words, whereas it was mid ([e], [ɛ], [ϕ] or [œ]) in the remaining words. Thus, half of the harmonic words—the ones containing high target vowels—were changed, in that they were produced in a disharmonized version (e.g., *eunuque* 'eunuch' [ϕnyk] → *eunique* [ϕnik]); likewise, half of the disharmonic words—the ones containing mid target vowels—were changed, in that they were produced in a harmonized version (e.g., *liqueur* → *liquère*). The other 176 harmonic (e.g., *pudeur*) and disharmonic (e.g., *laitue* 'lettuce' [lɛty]) words remained unchanged. For comparison, sample words and their realizations in both experiments by accent are shown in Table 2.

The items used for the test phase were identical to the ones in Experiments 1. Both in the set of exposure pairs and in the set of novel pairs, half of the items in each test list contained high target vowels, the remaining half mid target vowels.

Table 2
Sample harmonic and disharmonic French words with mid and high target vowels as realized in Experiments 1 and 2

	Exp. 1		Exp. 2
Word Type	Harmonic French	Disharmonic French	Mixed French
Harmonic			
Mid	pudeur	**pudère**	pudeur
High	eunuque	**eunique**	**eunique**
Disharmonic			
Mid	**liquère**	liqueur	**liquère**
High	**laitie**	laitue	laitue

Note. Modified words are shown in boldface.

3.1.3. Procedure

The procedure was identical to the one of Experiment 1, except that the stories were presented in Mixed French.

3.2. Results and discussion

Fig. 3 shows boxplots of participants' performance for exposure and novel items. Data were collapsed across Experiment 1 and 2 and analyzed using mixed-effect models as before.

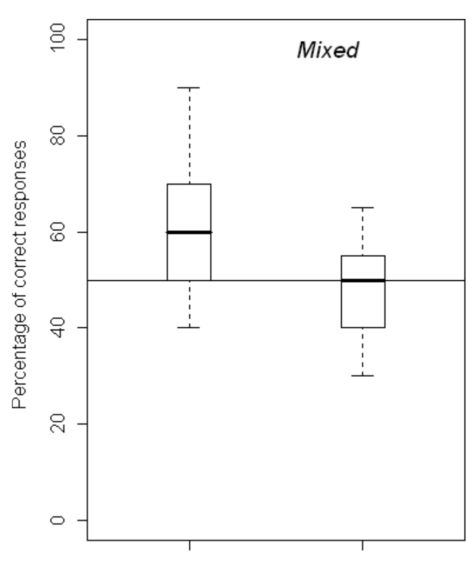

Fig. 3. Boxplot showing the percentages of correct responses by item type in Experiment 2. Whiskers indicate minimum and maximum values; the solid line represents chance performance (50%).

Table 3
Fixed effect part of the final model for novel items with Exposure Group (Harmonic, Disharmonic, Mixed) as fixed effect

Exposure Group	Coefficient (*SE*)	*z*-value	*p*-value
Harmonic	0.30 (0.13)	2.40	<.05
Disharmonic	0.29 (0.13)	2.24	<.05
Mixed	−0.07 (0.13)	−0.58	.56

The intercept values in the initial models (with random intercepts for participants and random slopes for items and without fixed effects) provide evidence that overall performance was significantly different from chance for both exposure items (Coefficient = 0.75, $SE = 0.12$, $z = 6.29$, $p < .001$) and novel items (Coefficient = 0.24, $SE = 0.06$, $z = 4.29$, $p < .001$). For exposure items, adding Exposure Group (Harmonic French, Disharmonic French, Mixed French) as a fixed effect did not provide a better fit in a likelihood ratio test comparing it to the initial model [$\chi^2(2) = 5.82$, $p = .05$]. For novel items, however, the extended model with the fixed effect Exposure Group did provide a better likelihood fit [$\chi^2(2) = 6.77$, $p < .05$] than the initial one, suggesting that there were differences in participants' performance according to the accent they were exposed to.

The fixed effect part of the extended model for novel items is summarized in Table 3. It shows that participants learning Harmonic French and Disharmonic French perform significantly better than expected by chance, but that the performance of learners of Mixed French is not significantly different from chance level. Re-referencing the extended model by taking the performance of the participants in the Mixed French group as a baseline for comparison revealed that both participants learning Harmonic French ($z = 2.0$, $p < .05$) and participants learning Disharmonic French ($z = 2.10$, $p < .05$) performed significantly better than participants in the Mixed French group.

Recall that correct responses for exposure items can be achieved both by remembering them from the stories and by applying the newly learned regularity. In contrast, correct responses for novel items necessarily involve the extraction of the regularity during exposure and its generalization across the lexicon. We can thus conclude that participants listening to Mixed French successfully memorized items from exposure, as indicated by their above-chance performance for exposure items, which was as good as the performance of the participants in Experiment 1. However, participants' at-chance performance for novel items in this experiment, which is significantly worse than the performance of participants exposed to either Harmonic or Disharmonic French in Experiment 1, suggests that participants can only adapt to this featurally complex accent in specific words that they are exposed to, but do not generalize it across the lexicon. That is, they fail to infer the context-dependent phonological regularities of Mixed French. This, then, is evidence that alternations are not learned individually for each sound pair, but as feature-based regularities applying to featurally similar groups of sounds.

4. General discussion

Using a naturalistic accent-learning paradigm with short exposure to stories in accented speech and a forced-choice identification task, we showed that French adults can learn novel context-dependent phonological alternations, such as vowel harmony and vowel disharmony. Hence, rapid adaptation to new varieties of the listeners' native language is not limited to phonetic category shifts (Maye et al., 2008), but extends to context-dependent phonological alternations. The size of the adaptation effect that we found (~10% for exposure items, 5% for novel items) is smaller than the one observed in Maye et al. (2008) (~20% overall). Several factors might account for this. First, the French participants in our study might be exposed less often to different accents that change the realization of vowels in their daily life than the American ones in Maye et al. (2008), and therefore have less experience with perceptual adaptation. Second, the design of our experiments differed from theirs in that we used a forced-choice identification task instead of lexical decision, and natural instead of synthetic speech. Third, even though more vowels in our accents were subject to change than in theirs (6 vs. 5), the changes in our accents were context dependent and hence occurred less often. Thus, although our participants were exposed to 40 min of accented speech and Maye et al.'s (2008) to only 20 min, it is possible that our participants received less evidence for the novel alternations. Finally, all else being equal, it might be harder to learn context-dependent changes than across-the-board category changes.

As in Maye et al. (2008), adaptation in the present study is not restricted to individual words; in fact, the effect generalizes across the lexicon in both studies. This generalization effect provides evidence that learning occurs not only on a word-specific lexical level but also on an abstract, phonological level. To our knowledge, no study on rapid learning of phonological variation has examined adaptation to novel phonological alternations; nonetheless, our result is in line with Scott and Cutler (1984), reporting (incomplete) perceptual adaptation to novel alternations in nonnative dialects after several years of exposure.

As we used an accent identification task, we cannot conclude at which level of phonological processing—lexical or prelexical—the adaptation occurred. That is, although during exposure participants had to treat the accented words as phonetic variants of existing words in order to understand the stories, during the test phase they may merely have identified harmonic or disharmonic surface patterns in the items presented to them. Other adaptation studies, however, found evidence that participants do link accented words to representations of existing words: In Maye et al.'s (2008) study participants accepted accented words more readily as real words after exposure than before in a lexical decision task. Similarly, Dahan, Drucker, and Scarborough (2008) studied adaptation to a dialect of American English in which [æ] is raised to [ɛ] before voiced consonants; they found that exposure to accented words (e.g., bag [bɛg]) affects competition effects arising during the recognition of unaccented words (e.g., back [bæk]), suggesting that the whole system of lexical representation can be altered by exposure to accented speech. In order to establish at which level the adaptation effects occur in our paradigm, further experiments using tasks that involve lexical access, such as lexical decision (with or without priming), are needed.

Another question that remains open is whether the newly learned alternations are treated as idiosyncrasies of a single talker or as a new dialect potentially shared by many speakers. Like most previous studies on phonetic learning (e.g., Maye et al., 2008; Norris et al., 2003), we used only one talker. However, a recent multitalker study by Kraljic and Samuel (2007) on phonetic category shifts suggests that some, but not all, adaptation effects extend to novel talkers: Participants in their experiments generalized the category shift induced by ambiguous sounds between [d] and [t] to a new voice, but not the one induced by ambiguous sounds between [s] and [ʃ]. They argue that this difference is due to the fact that the temporal-voicing cue to the [d]-[t] distinction does not provide local, acoustic, information about the talker, whereas the spectral-place cue to the [s]-[ʃ] distinction does. Given that rounding distinctions on vowels are likewise dependent upon spectral information, this would suggest that participants in our experiments might treat the newly learned vowel rounding alternations as idiosyncrasies of a single talker. In order to test this, the experiments could be repeated with recordings of different talkers pronouncing the exposure stories and the test items, respectively.

The present study also investigated the learning mechanisms that allow for rapid dialect adaptation. Each experiment addressed a particular question in this regard. Experiment 1 assessed whether there are differences between the learning of vowel harmony, a cross-linguistically well attested and phonetically motivated sound pattern, and the learning of vowel disharmony, a less well attested pattern with no obvious phonetic motivation. We found that vowel harmony and disharmony are equally learnable, at least in the present paradigm and with the present amount of exposure. Provided young children show the same behavior, this suggests that the cross-linguistic preponderance of vowel harmony over disharmony does not stem from a linguistic bias favoring harmony over disharmony in perceptual phonological learning.

An alternative explanation of this typological asymmetry is provided by theories in which typological facts are the result of diachronic sound changes (Blevins, 2004; Bybee, 2001; Ohala, 1993). In particular, vowel harmony has its roots in universal vowel-to-vowel coarticulation, which makes it quite likely to be introduced into a language (Blevins, 2004). Vowel disharmony, by contrast, does not have such a universal phonetic precursor and is thus less likely to arise over time.

However, our results do not completely rule out a synchronic explanation. Typological asymmetries are often explained by phonetically motivated biases in the speaker's mind (Archangeli & Pulleyblank, 1994; Donegan & Stampe, 1979; Hayes & Steriade, 2004), but most theories do not specify whether these apply in perception, production, or both. If some biases were restricted to production, they could still account for the fact that vowel harmony is more common than vowel disharmony in the world's languages. Specifically, as vowel harmony facilitates the *pronunciation* of neighboring vowels, its preponderance might stem from an ease-of-articulation constraint. Warker, Xu, Dell, and Fisher (2009) indeed provide evidence that phonological learning tends to be modality specific. In their study, participants listened to nonwords, some of which they had to repeat. Over several experimental sessions, their speech errors came to reflect properties of the nonwords they had previously produced, not properties of the nonwords they had only heard. Several other findings support the hypothesis that synchronic biases are restricted to production. Peperkamp and colleagues explicitly compared perception and production tasks in a series of artificial language learning studies. Using the same materials and exposure, they found a better performance for cross-linguistically common phonological alternations than for inexistent ones with a production task (Peperkamp, Skoruppa, & Dupoux, 2006), but not with a perception task (Peperkamp & Dupoux, 2007). More generally, several artificial language learning studies using a production task have found better performance for common phonological alternations (Schane, Tranel, & Lane, 1974; Skoruppa, Lambrechts, & Peperkamp, in press; Wilson, 2006)—which in some cases increased ease of articulation (Schane et al., 1974; Wilson, 2006)—than for uncommon ones, whereas no such advantage was found in a study using a perception task (Pycha et al., 2003).

It would be interesting to use the same materials and exposure as in the present study to examine the learning of vowel harmony and disharmony with a production task.[6] If, contrary to the present results, an advantage for vowel harmony is found in production, this would be evidence for an ease-of-articulation constraint affecting production only. If, however, vowel harmony and disharmony are not only equally well learned and applied in perception, but also in production, a diachronic account would be supported.

Experiment 2 asked whether phonetic features play a role in phonological learning. We used a featurally more complex mixture of harmony and disharmony and found that participants performed above chance level for words known from exposure but not for novel words. Thus, adaptation to the mixed regularity was item specific and did not generalize across the lexicon, at least not with the present amount of exposure. The difference between the results of Experiments 1 and 2 provides evidence that learners extract regularities by means of feature-based inferences: While the regularities of the three accents have the same complexity if features are disregarded, the regularity of Mixed French is more complex than those of Harmonic and Disharmonic French from a featural point of view. This is because neither the set of rounded nor the set of unrounded targets is homogeneous with respect to the contexts in which they occur in Mixed French: Some rounded vowels occur after rounded vowels, others after unrounded ones, and likewise for the unrounded targets. Learners of Mixed French thus have to make two rather than one feature-based inference. Moreover, for each of these inferences they are exposed to only half the amount of input of what was provided for the feature-based inferences concerning harmony and disharmony. This, then, explains why their performance is worse than that of learners of either Harmonic or Disharmonic French.

Hence, the present study extends the existing evidence for feature-based learning in artificial languages (Endress & Mehler, 2010; Finley & Badecker, 2009; Kuo, 2009; Pycha et al., 2003; Wilson, 2006) to the adaptation to novel accents containing context-sensitive phonological regularities. Note, however, that we cannot conclude from the present study whether featurally complex alternations such as the ones used in Experiment 2 cannot be learned at all, or whether they are only harder to learn than featurally more simple ones, as we do not know whether participants would succeed with longer exposure. An artificial language learning study by Onishi, Chambers, and Fisher (2002) hints to the possibility that the latter might be true: Their participants successfully learned phonotactic constraints that applied to featurally arbitrary sound groupings such as [b,t,k,f,m], suggesting that featurally complex phonological patterns are not unlearnable. Future research should investigate whether this result for phonotactic learning extends to the learning of alternations.

The question of whether learning is based on the use of *abstract*, phonological, features also remains to be investigated. Phonological theories have made many different proposals with respect to the nature of features (for an overview, see Clements, 2006), but given that most features have quite consistent articulatory and/or acoustic correlates, language learners might base their inferences on articulatory and/or acoustic similarity without using abstract feature representations.

To conclude, we have shown that listeners can quickly adapt to context-dependent phonological regularities in novel accents, making feature-based inferences. More research is necessary to investigate whether this adaptation extends to novel speakers, and to examine the nature of feature representations in adult learners.

Notes

1. We know of only one language, Ainu, with a productive vowel disharmony process (Kraemer, 1998).
2. The only vowel harmony process attested in French is regressive height harmony of mid vowels; this alternation, however, is phonetically incomplete and shows a lot of interindividual variation (Nguyen & Fagyal, 2008).
3. The speaker read written versions of the stories in which the spelling of the modified words reflected the vowel changes. In order to verify that the changed vowels had been produced correctly, we excised one-third of the syllables with a changed vowel from the stories in both Harmonic and Disharmonic French, and asked a native speaker of French to transcribe the vowels she heard. The transcriptions corresponded to the intended vowels in 98% of the cases.
4. Note also that during an informal debriefing after the experiment, participants were unable to explicitly report the regularity they had learned. While claiming to have recognized some exposure words, most participants stated that their replies for the novel words were based on guessing.
5. There are of course other possibilities. In the most extreme case, the regularity could be learned as the conjunction of 18 different statements, each concerning the occurrence of one of the six target sounds in one of its three vowel contexts.
6. Note, though, that differences observed with perception and production tasks could also be due to differences in their cognitive load (Peperkamp et al., 2006).

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Supporting Information

Additional Supporting Information may be found in the online version of this article on Wiley InterScience:

Appendix S1. Test items: Exposure items.

Appendix S2. Test items: Novel items.

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