Learning Unattested Languages

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Abstract

This paper demonstrates the role of morphological alternations in learning novel phonotactic patterns. In an artificial grammar learning task, adult learners were exposed to a phonotactic pattern in which the first and last consonant agreed in voicing. Long-distance phonotactics encoded as strictly piecewise languages suggest that first-last phonotactic patterns should be unattested in natural language. However, recent theories of morphologically induced phonological patterns predict that long-distance agreement between the first and last consonant of a word can occur when the agreement is induced as a morphological alternation. The results of two experiments support the prediction that first-last harmony patterns are more easily learned when morphological cues to the pattern are present. Participants only learned the first-last pattern when presented as a morphological alternation.

Keywords: statistical learning, phonotactics, morphology.

Introduction

One of the major goals of generative linguistics is to explain the nature of language in terms of computational constraints on the cognitive capacity for human languages. Computational models of phonotactic patterns work to understand the restrictions that underlie the set of patterns that are possible in natural language and the set of patterns that are not possible. Recent work has argued that phonotactic patterns, defined as constraints on the co-occurrence of different sounds within a word, are subject to a very specific set of computational constraints (Heinz, 2007, 2011a, 2011b). In particular, it has been demonstrated that long-distance phonotactic patterns derived from consonant harmony can be simulated using strictly piecewise languages (Heinz, 2010; Heinz & Rogers, 2010; Rogers et al., 2010), a subset of regular languages.

Computational models of phonotactic patterns raise three important questions for a theory of the cognitive science of language. First, is there a correlation between the patterns that are learnable and the patterns that can be generated by computational models? There is a prediction that any long-distance consonant agreement pattern that does not fall within the set of strictly piecewise languages should not be learnable. Second, do computational models of phonotactic patterns capture the intricacies of generative models of phonological representations? If morphological and syntactic constructions require more complex computational machinery to generate, then there is a question of whether patterns at the interface between phonology and morphology, and phonology and syntax are subject to the same computational constraints as purely phonotactic patterns (Heinz & Idsardi, 2011). Third, is there a way to reconcile apparent exceptions to general tendencies linguistic typology? Linguistic tendencies are typically proposed as opposed to universals because almost any 'universal' has exceptions (Evans & Levinson, 2009).

These questions are particularly salient for a specific, hypothetical phonotactic pattern: first-last agreement (Lai, 2012). For the purposes of this paper, a first-last agreement pattern is any phonotactic pattern in which the first and last segment in a word must agree in terms of some phonological feature. For example, a first-last consonant voicing pattern requires that the first and the last consonant in a word share the same value for the feature [Voice]. In such a pattern, the word [boteg] would be a possible word because the first consonant ([b]) and the last consonant ([g]) are voiced, even though the medial consonant ([t]) is voiceless. However, *[boget] would not be a possible word because the first consonant ([b]) is voiced and the final consonant ([t]) is voiceless.

First-last patterns are said to be unattested in natural language (Lai, 2012). One possible explanation for the failure to find a true case of first-last agreement is that such patterns can not be generated with a strictly piecewise grammar (Heinz & Rogers, 2010). If long-distance phonotactic patterns must be generated with a strictly piecewise grammar, patterns that fall outside of the cognitive constraints on phonological patterns may not be learnable.

While purely phonotactic first-last patterns have not been described in natural languages, there are some possible cases of first-last agreement patterns when morphology is considered. A morphologically controlled phonological alternation is any sound pattern that occurs only in the presence of a specific morphological environment. For example, the alternation between /o/ and /e/ in 'goose' vs. 'geese' is induced by the alternation between singular and plural. Such morphologically controlled patterns may manifest as a first-last agreement pattern. For example, in Lokaa, a Benue-Congo language spoken in Nigeria, the future tense is marked with a low tone on the final syllable and a prefix containing a low tone (e.g., [nà-à-fúkà] 'you will gather'). In this case, the first and last vowels of a word must agree in tone, but only in the future tense. (Iwara, Akinlabi, & Truckenbrodt, 2003). Finley (2009) accounts for this morphological alternation using morpheme-specific constraints that target specific edges of the word. Finley's analysis suggests that morphologically controlled patterns, also referred to as 'featural affixation', are subject to different constraints than purely phonotactic patterns. The possibility that featural affixation can target the first and last element of a word leads to the prediction that long-distance patterns that cannot be generated with a strictly piecewise model of phonotactics may be generated at the interface between phonology and morphology.

There are three reasons to believe that phonotactic patterns and morphologically controlled phonological patterns are subject to different representational and learning constraints. First, as discussed above, the typological restrictions on morphologically controlled patterns tends to be more open than the restrictions placed on phonotactic patterns (Finley, 2009). Second, infants appear to learn phonotactic patterns earlier than morphologically controlled phonological patterns (Jusczyk, Friederici, Wessels, Svenkerund, & Jusczyk, 1993). Third, Lai (2012) demonstrated that adult learners are worse at learning a first-last consonant agreement pattern than a typical consonant harmony pattern that targeted all relevant segments of the word.

The problem with understanding the difference between morphological and phonotactic patterns in terms of representation and typology is that there are reasons why the typology of phonotactic constraints may be different from the typology of morphologically controlled phonological patterns. For example, the lack of existence of a first-last phonotactic agreement pattern may reflect constraints on phonotactic representations, or it could simply reflect an accidental gap. In addition, phonotactic patterns may be learned faster than morphologically controlled phonological patterns because phonotactic patterns apply to a large range of words, while morphologically controlled patterns only apply to specific morphological environments. In this case, the infant must learn both the phonological pattern, but also the morphological environment.

One possible way to understand the relationship between typological and computational constraints on long-distance phonotactic patterns is to explore the existence of learning biases for long-distance patterns. Previous research suggests that first-last phonotactic agreement patterns may not be learnable (Lai, 2012). While Onnis, Monahan, Richmond, and Chater (2005) showed learning of first-last phonotactics, this pattern was based on syllables, rather than features, and therefore may be subject to different constraints. However, there is a question of whether adults may be able to learn first-last agreement patterns if they are presented as a morphologically controlled phonological alternation. In an artificial grammar learning task, it is possible to compare learners with the same language backgrounds (American English) with two languages that are minimally different (phonotactic first-last agreement vs. morphologically controlled first-last agreement). If morphologically controlled patterns are subject to different constraints on learning and representation, one should expect that in the case of first-last agreement patterns, morphologically controlled patterns should be easier to learn than a phonotactic agreement pattern. This prediction is particularly interesting because it goes against the general findings that phonotactic patterns are learned before morphological patterns. In an artificial grammar learning paradigm, adult participants were exposed to a first-last agreement pattern that was induced either as a morphological alternation or as a phonotactic pattern. Participants who were exposed to the pattern as a phonotactic pattern did not differ significantly from chance or control participants. This is similar to Lai's (2012) results, which showed that an unattested first-last agreement pattern is less easily learnable than a version of an attested consonant harmony pattern. However in the study reported here, participants were exposed only to the first-last agreement pattern, either presented as a phonotactic constraints or as part of a morphological alternation.

Experiment 1

Participants

All participants were adult native speakers of English with no previous exposure to a language involving first-last agreement or consonant harmony. Forty-six University of Rochester undergraduate students and affiliates and were paid $10 for their participation. Two additional participants were from the Elmhurst College Psychology Department Human Subject Pool, and were given extra course credit for their participation.

Design

Participants were trained on a first-last voicing agreement pattern via auditory exposure. In this pattern, the first and the last consonants of every word agreed in voicing. All words were of the form CVCVC, where C refers to stop consonants drawn from the set /p, t, k, b, d, g/, and V refers to vowels drawn from the set /i, e, o, u, a/. The first and last consonants were either both voiced /b, d, g/ or both voiceless /p, t, k/, with no restriction on the voicing of the medial consonant.

Participants in the Morphological Training condition were exposed to 24 pairs of CVCVC items (repeated five times each) in which the first CVCVC item contained voiceless stops in the first and last positions and the second item contained voiced consonants in the first and last positions (e.g., /**k**ida**t** **g**ida**d**/ and /**t**opa**k** **d**opa**g**/). Participants in the Morphological Training condition were told that they were listening to a novel language, and that they would hear pairs of words, the first of which was a 'singular' form and the second of which was a 'plural' form. The use of 'singular' and 'plural' labels was designed to create the effect of a morphologically controlled alternation. Because adult English speakers are familiar with the distinction between singular and plural, it was assumed that participants recognized that the pairs of items were morphologically related. There was no other semantic information accompanying the training items.

Participants in the Phonotactic Training condition were exposed to the same 48 words that were presented to the participants in the Morphological Training condition, and were told that they would be listening to words from a novel language. There were two main differences between the

Morphological Training condition and the Phonotactic Training condition, reflecting the two main differences between phonotactic and morphologically controlled phonological patterns. First, participants in the Phonotactic training condition were given no semantic information about the items. Second, items in the Phonotactic Training condition were not presented as pairs of items, but as single words presented in a random order.

The medial consonant varied between voiced and voiceless such that half of the items showed voicing agreement for all consonants, and the other half of exposure items showed voicing agreement only between the first and last consonant. In addition, the distribution of consonants was even, such that each consonant appeared in an equal number of items in both final and initial positions. One third of training items contained identical consonants in both first and last positions Examples of the training stimuli can be found in Table 1.

Table 1: Example Training Items.

Voiceless	Voiced
kida**t**	**g**ida**d**
topa**k**	**d**opa**g**
pibo**t**	**b**ibo**d**

In the Morphological Training condition, all 'singular' words had voiceless consonants in first and last positions, and all 'plural' words had voiced consonants in the first and last positions. There are two reasons why this design was chosen (as opposed to adding a suffix that alternated depending on the quality of the first consonant, as in /kida-kidat, dopa-dopad/). First, the present design allows the Morphological Training and the Phonotactic Training conditions to use the exact same set of training items, as opposed to two different sets for each condition. Second, the voiceless-voiced alternation mirrors the morphological harmony patterns described in Finley (2009). For example, Kanembu shows an alternation in which the incompletive form are all [–ATR], while the completive forms are all [+ATR] (Akinlabi, 1996).

Following exposure, all participants were given a two-alternative forced choice test. This test was designed to probe whether participants had learned the agreement pattern. All participants received the same set of 40 test items that contained ten Old Items (items heard in the training set), ten New Items (items not heard in the training set), and 20 filler items that contained the voiceless alternation.

All test items were of the form CVCVC in which the 'correct' (harmonic) item contained a voiced consonant in the first and the last position of the word, and the 'incorrect' (disharmonic) item contained a voiced segment in the first position and a voiceless consonant in the final position. Examples of test items can be found in Table 2, below.

Participants in both training conditions were given identical instructions for how to complete the test phase. Participants were told that they would hear two words. One word was from the language they had just heard, and the other word was not from the language they had just heard; if they believed the first word was from the language, they were instructed to press the 'a' key; if they believed the second word was from they language, they were instructed to press the 'l' key. Participants did not hear pairs of words in the test phase.

Table 2: Example Test Items.

Old Items	
Harmonic	Disharmonic
gida**d**	**g**ida**t**
dopa**g**	**d**opa**k**
New Items	
Harmonic	Disharmonic
bika**d**	**b**ika**t**
depo**d**	**d**epo**t**
gutu**b**	**g**utu**p**

A female native speaker of English produced the spoken materials that were used in the experiment, and had no knowledge of the design or purpose of the experiment. The speaker produced all sounds in a sound-attenuated booth. All bi-syllabic stimuli were produced with stress on the first syllable, but instructions were given to the speaker to pronounce all vowels (as English vowels in unstressed position tend to be reduced). All stimuli items were normalized for intensity (set at 70dB) using Praat (Boersma & Weenink, 2005).

All phases of the experiment were run in Psyscope X (Cohen, MacWhinney, Flatt, & Provost, 1993). Participants were given both written and verbal instructions. The entire experiment took approximately 20 minutes.

Results

Proportion of correct responses (i.e., choosing the item that contained a voiced stop in the first and last position) for all conditions are given in Figure 1. Responses were compared via a 2x2 mixed design ANOVA. There was a significant effect of Training, $F(1, 34) = 4.24$, $p < 0.05$, in that participants in the Morphological Training condition (mean = 0.63, $CI \pm 0.084$) selected the harmonic option more often than participants in the Phonotactic Training condition (mean = 0.51, $CI \pm 0.085$). There was no effect of Test Item, $F<1$, and no significant interaction, $F(1, 34) = 2.30$, $p = 0.14$.

Responses to Old and New items were compared to 50% chance via Bonferroni corrected one-sample t-tests. There was a significant effect in the Morphological Training condition for both Old Items, with a mean of 0.64, $CI \pm 0.11$, $t(17) = 2.75$, $p < 0.05$, and New Items, with a mean of 0.62, $CI \pm 0.083$, $t(17) = 2.99$, $p < 0.01$. This suggests that participants in the Morphological Training condition learned the harmony pattern at a level greater than chance. There was no significant differences in the Phonotactic Training condition for either Old Items, with a mean of 0.47, *CI* ± 0.12, $t(17) = -0.49$, $p = 0.63$, or New Items, with a mean of 0.54, *CI* ± 0.082, $t(17) = 1.14$, $p = 0.27$. This suggests that participants in the Phonotactic Training condition failed to learn the harmony pattern at a level greater than chance.

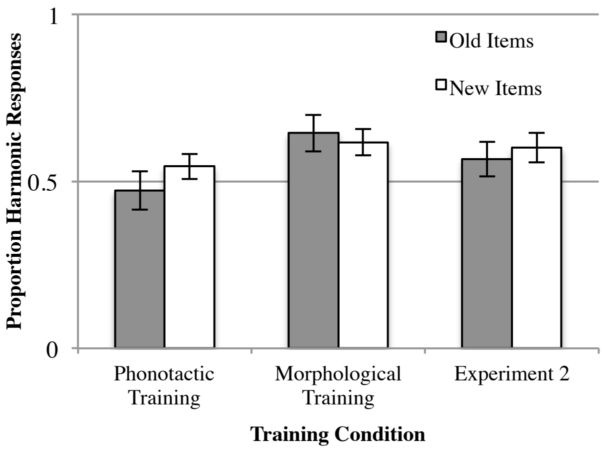

Figure 1: Results.

It is important to note that the success of the participants in the Morphological Training condition was not limited to correct items that were fully harmonic. Participants in the Morphological Training condition selected the correct item 64%, of the time when the medial item was voiceless and the first and last item was voiced (e.g., /beteg/), *CI* ± 0.11, $t(17) = 2.86$, $p = 0.011$ (because of the small number of items, Old and New items were combined in this analysis, with a mean of 67% for Old items and 59% for New Items). This analysis rules out the possibility that participants only learned a harmony pattern that required all consonants to share the same feature for voicing.

There was a high amount of individual variation in the present experiment. Three of 18 participants in the Morphological Training condition showed a mean below 50%, while nine of the 18 in participants in the Phonotactic training condition showed a mean lower than 50%. The fact that so many participants in the Phonotactic Training condition scored below chance suggests that these participants were not attending to the relevant aspects of the stimuli. These participants may have simply been ‘guessing’ incorrectly more often than correctly, or they may have inferred a pattern that was not actually present in the data.

The results of the present experiment support the hypothesis that a first-last agreement pattern is more easily learnable as a morphologically controlled phonological alternation than as a phonotactic pattern. Participants in the Morphological Training condition responded correctly to harmonic items at a level greater than chance, and significantly outperformed participants in the Phonotactic Training condition, who failed to learn the first-last agreement pattern.

There were two major differences between the Morphological Training condition and the Phonotactic Training condition. First, participants in the Morphological Training condition received information about the morphological status of the items in the training (singular-plural pairs). Phonotactic patterns are not morphologically restricted, and morphological information is therefore irrelevant to the phonotactic pattern. Second, the training items in the Morphological Training condition were presented as pairs of words, voiceless followed by voiced. This reflects the fact that morphologically controlled phonological alternations are typically described in terms of an alternation. While both pieces of information are necessary to differentiate between phonotactic patterns and morphologically controlled alternations, it is unclear whether the unattested phonotactic first-last agreement pattern might be learnable if words were simply presented as pairs of words that differed in voicing. Presentation of items as pairs of words may highlight the regularities present in the word, regardless of the morphological status of the pairs of words. Experiment 2 tests whether adult English speakers are able to learn the unattested phonotactic first-last alternation if the items are presented in pairs of voiceless-voiced ‘alternations’ without morphological information.

Experiment 2

Participants

All participants were adult native speakers of English with no previous exposure to consonant harmony. All 18 participants were Elmhurst College undergraduate students, recruited from the Elmhurst College Psychology Department Human Subject Pool, and were given extra course credit for their participation.

Design

Participants in Experiment 2 were given the same exposure items as participants in the Morphological Training condition in Experiment 1. Participants were exposed to 24 pairs of items that reflected an alternation between CVCVC words in which the first and last consonants agreed in voicing; the first word of each pair contained voiceless stops, and the second word of each pair contained the corresponding voiced stops. Unlike Experiment 1, participants in Experiment 2 were not given any information about the morphological status of the pairs of items. Participants were simply told that they would be listening to words from a novel language. They were not told that the items were presented in pairs. Participants in Experiment 2 received the same test items as participants in Experiment 1.

Results

Proportion of correct responses (i.e., choosing the item that contained the voiced stops in first and last position) were recorded, and are present in Figure 1, above.

Responses to Old and New items were compared to 50% chance via Bonferroni corrected one-sample t-tests. There was no significant effect for Old Items, with a mean of 0.57, *CI* ± 0.11, $t(17) = 1.27$, $p = 0.22$. There was, however, a marginal difference for New Items, with a mean of 0.60, *CI* ± 0.093, $t(17) = 2.26$, $p = 0.074$. These results suggest that participants in Experiment 2 did not reach full criterion for learning, but did show some evidence of learning beyond the chance level.

In addition, a 2x3 ANOVA was performed comparing results for Experiment 1 with results for Experiment 2. There was a marginal effect of Training, $F(2, 51) = 2.21$, $p = 0.080$, no effect of Test Item, $F<1$, and no significant interaction $F(1, 51) = 1.10$, $p = .34$. Pairwise comparisons revealed no significant differences between Experiment 2, with a mean of 0.58, *CI* ± 0.084, and the Phonotactic Training condition of Experiment 1, $p = 0.21$, or the Morphological Training condition of Experiment 1, $p = 0.42$. These lack of significant differences suggest that participants in Experiment 2 performed at a level intermediate between that of the Phonotactic Training condition and that of the Morphological Training condition in Experiment 1.

There are potentially many reasons why participants in Experiment 2 did not perform significantly different than either the Morphological Training condition or the Phonotactic Training condition. First, it is possible that some of the learners imposed morphological structure on the pairs of words. In informal debriefing, several participants noted that they had analyzed the pairs of words as being related 'like singular and plural'. If some learners naturally impose morphological structure on alternating pairs of words, it would suggest that learners use morphological cues when they have the potential to be helpful. Second, it is possible that the presence of cues to a morphologically controlled phonological pattern (alternations and morphological information) provide the best learning environment for the most people. If only one of the cues is present, learning will be intermediate between having both cues and no cues at all. Third, it is possible that the high degree of individual differences across both experiments made finding a significant effect difficult. Of the 18 participants in Experiment 2, five showed means lower than 50%. These individual differences may have been compounded the additional factors that lead to an intermediate result for Experiment 2. Fourth, the lack of a difference may simply reflect a floor effect. It may be difficult to show substantial differences between training conditions, due to the fact that learning in the Morphological Training condition of Experiment 1 was significant, but not highly robust.

Discussion

The present study explored the role of alternations and morphological information in learning phonotactic patterns. First-last agreement patterns, which fall outside of the strictly piecewise grammars, are predicted to be unlearnable (Heinz 2010; Lai, 2012). However, linguistic analyses that demonstrate the possibility of a morphologically controlled alternation that targets the first and last segments of a word (Finley, 2009), along with the existence of morphologically controlled first-last agreement patterns, leads to the prediction that morphologically controlled phonological patterns may not be subject to the same constraints on learning and representation as purely phonotactic patterns. This prediction was tested using an artificial grammar learning paradigm in which adult native English speakers were exposed to an artificial first-last agreement pattern that was either presented as a morphological alternation or as a phonotactic alternation. Participants failed to learn the phonotactic pattern, but successfully learned the morphologically controlled phonological alternation. This result suggests that unattested phonotactic patterns may be possible given the right morphological cues.

The results of the present experiment have important consequences for theories of typological linguistic universals. One of the major issues with proposing a linguistic universal is that it is very difficult to interpret potential counter-examples, or a lack of counterexamples (Evans & Levinson, 2009). For example, if there are no cases of first-last agreement patterns in natural language, is it because of a cognitive restriction or because of an accidental gap? In the case of first-last agreement patterns, potential counter-examples can often be 'explained-away' in terms of morphological restrictions. Using an artificial grammar learning paradigm, it is possible to tease apart issues of the source of a typological restriction (Nevins, 2009). First, if two patterns that are minimally different except for a predicted restriction on language, there is a clear prediction that one pattern will be learned more easily than the other. For example, Finley (in press) compared learning between minimally different vowel harmony languages. One language had typologically (and phonetically) salient mid vowels as the source for harmony, while the other language had typologically (and phonetically) less salient high vowels. Participants who were exposed to the typologically salient cues were able to learn the harmony pattern, while participants who were exposed to the less salient cues failed to learn the pattern. Second, it may be possible to find explanations for potential counterexamples to proposed linguistic universals. Additional social and cognitive cues may support learning a pattern that falls outside a predicted learning space. Artificial grammar learning experiments provide a mechanism to control for these factors. In the present study, it was demonstrated that the proposed restriction that strictly piecewise languages patterns form part of the cognitive constraints on phonological grammars may not hold in the case of morphologically controlled alternations.

Jusczyk and colleagues (1993) suggest that infants may learn phonotactic patterns faster than morphological ones. This appears to be at odds with the results of the present study, in which the morphologically controlled pattern was learned with greater ease than the phonotactic pattern. There are two possible explanations for this difference. First, the present study addressed phonotactic patterns that are outside of the range of naturally occurring attested phonological patterns. Thus, it may be possible that phonotactic patterns are easier to learn that morphologically controlled alternations, but only when the phonotactic pattern falls within the set of strictly piecewise languages. Second, the artificial nature of the present study may have provided a shortcut to learning. Participants were told that they were hearing morphological alternations. In a natural learning situation, the learner has to discover both the morphological component to the pattern as well as the phonological component. Infants may be better at learning phonotactic constraints simply because there is less information to attend to. Adults in a language learning task can use morphology as a cue to learning in a way not possible in infant language learning.

The present study leaves open the question of why morphologically controlled phonological alternations might allow for a larger range of possible languages than phonotactic patterns. One possibility is that morphology provides additional cues to learning that may not be possible when learning a purely phonotactic pattern. This falls in line with theories that predict that metalinguistic cues such as social factors and communicative intent play an important role in the typology of language and language learning. Another possibility is that the computational power of morphological and syntactic processes exceeds that of purely phonotactic patterns. Thus, patterns at the interface of phonology and morphology/syntax may thus fall outside of the computational power of purely phonological patterns (Heinz & Idsardi, 2011). If this is the case, there is a question of how to integrate phonotactic patterns at the interface between morphology and syntax.

This issue has important implications for computational models. If morphologically controlled phonological patterns are governed by a different set of constraints than phonotactic patterns, there is a question of how to incorporate both into a computational model of language and language learning. The ultimate goal of linguistics is to provide a model of language that explains the mechanisms that underlie the processes that are found (and are not found) in natural language that is both cognitively plausible and computationally elegant. Understanding the factors that learnability of various types of phonological patterns will ultimately lead to an understanding of the cognitive capacity for language.

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