

**Phonotactics and alternations:
Testing the connection with artificial language learning***

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ABSTRACT

Phonological alternations often serve to modify forms so that they respect a phonotactic restriction that applies across the words of a language. Since Chomsky and Halle (1968), it has been assumed that an adequate theory of phonology should capture the connection between phonotactics and alternations by deriving them using a shared mechanism. There is, however, no psycholinguistic evidence that speakers actually do use a single mechanism to encode phonotactics and alternations. In this study, we used an artificial language learning experiment to test whether an alternation that meets a phonotactic target is easier to learn than one that does not. The two groups of adult subjects learned mini-languages that differed only in whether the alternations were motivated by the phonotactics of their native language. The results suggest that phonotactic knowledge does aid in the acquisition of alternations, and also provide a novel example of the influence of the first language on second language learning.

1. Introduction

The phonotactics of a language restrict its set of possible sound sequences. One phonotactic generalization of English is that words cannot end with a sequence of a

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² In fact, the restriction is broader: tautosyllabic obstruent clusters must share a single voicing specification (i.e. [+voice][-voice] sequences are banned too).

voiceless obstruent followed by a voiced one (see (1a) below)²; another is that English monosyllabic words cannot have a rime which consists only of a lax (short) vowel, as in (1b):

- (1) a. *No [-voice]/[+voice] obstruent sequences:*
 *[bæpʒ] *[fowtʒ] *[hikd]
 cf. [bæps] [fowts] [hikt]
- b. *No monosyllabic CV words:*
 *[bli], *[gɛ], *[flʊ]
 cf. CVV: [blij], [gej], [fluw]; CVC: [blɪt], [gek], [flud]

The phonological *alternations* of a language are the changes in the shape of morphemes that depend on their phonological context. In English, the plural and past tense morphemes show a voicing alternation depending on the last consonant of the root, as illustrated in (2):

- (2) a. *Plural alternation between [z] and [s]*
 dog[z], job[z], rod[z] vs. dock[s], mop[s], lot[s]
- b. *Past tense alternation between [d] and [t]*
 rob[d], log[d], buzz[d] vs. dock[t], lop[t], miss[t]

Another English alternation holds between [k] and [s] in front of certain suffixes:

- (3) *Velar [k] at the end of Latinate stems: Alternating with [k] before -ity, -ism:*
 electri[k], lyri[k], romanti[k] electri[s]ity, lyri[s]ism, romanti[s]ism

The phonotactic generalizations in a language are often connected to its alternations in that the alternations enforce phonotactic well-formedness by eliminating structures that are also absent from the language's lexicon. For example, the voicing alternation in (2) ensures that plurals and past tense forms of English conform to the general phonotactic restriction in (1a).

This connection between alternations and static phonotactics was recognized by Chomsky and Halle (1968):

- (4) ...regularities are observed within lexical items as well as across certain boundaries – the rule governing voicing of obstruent sequences in Russian, for example – and to avoid duplication of such rules in the grammar it is necessary to regard them not as redundancy rules but as phonological rules that also happen to apply internally to a lexical item. (p. 382)

Subsequent research cast doubt on the viability of a purely rule-based approach to the duplication problem, and this became one of the early arguments for the introduction of


constraints into phonological theory (see especially Kenstowicz and Kisseberth 1977, 1979).

In Optimality Theory (OT; Prince and Smolensky 1993/2004), the duplication problem is solved by deriving phonotactics and alternations from a single set of constraints (McCarthy 2002; Hayes 2004). An OT grammar of English assumes a ranking like the one in (5) below, where a Markedness constraint AGREE[VOICE], which requires that adjacent obstruents match for voicing, ranks above the Faithfulness constraints against changing input voicing:

- (5) *An English ranking*
 AGREE[VOICE] >> FAITH[VOICE]


This ranking will enforce the English phonotactic restriction in (1a). Static phonotactics are dealt with in OT by having the grammar act as a filter. The grammar of a language should be able to take any underlying form as an input, and yield an output that conforms to the languages' phonotactics (Richness of the Base, Prince and Smolensky 1993). In the case at hand, any underlying input with a [-voice][+voice] obstruent sequence, like /boopz/ in (6) below, will be transformed to one with matching voicing (6b), which satisfies AGREE[VOICE]. The faithful candidate (6a) is ruled out because FAITH[VOICE] ranks beneath AGREE[VOICE]:

(6)

/bæpz/	AGREE[VOICE]	FAITH[VOICE]
a. bæpz	*!	
b.  bæps		*

In addition, the same ranking will drive the alternation between the plural allomorphs [z] ~ [s]. Given a voiceless-final stem and a plural morpheme /z/, AGREE[VOICE] will again rule out the mismatched candidate (7a), and choose voicing assimilation for the winner (7b):³

(7)

/bʊk/ + /z/	AGREE[VOICE]	FAITH[VOICE]
a. bʊkz	*!	
b.  bʊks		*

2. The connection between phonotactics and alternations in acquisition

While there is much agreement amongst phonologists that an adequate theory of phonology should deal with the duplication problem, it remains an open issue whether language learners – either of first or second languages – do use a unified mechanism to encode phonotactics and to generate alternations.

³ For a recent OT treatment of English word-final alternations in voicing, see Bakovic (2004).

One reason that one might be doubtful about the existence of a tight link between phonotactics and alternation is due to the fact that there are alternations that serve no phonotactic aim. In English, velar softening produces an alternation between final [k] ~ [s], as in (8a) below. However, this alternation does not seek to match any phonotactic restriction of English. It is not the case that underlying /k/ is becoming [s] due to a phonotactic demand, since [k] is allowed in this environment (e.g. ric[k]ety).

- (8) a. *Velar softening alternation...* b. *... with no phonotactic motivation*
 electri[k] vs. electri[s]ity c.f. ric[k]ety, cate[k]ism
 lyri[k] vs. lyri[s]ism

Pierrehumbert (to appear) presents *wug*-test results showing that English speakers do have productive knowledge of velar softening. This means that they did learn the alternation, even without phonotactic support. By extension, it could be argued that all alternations are learned from raw observation of changes in the phonological structure of morphemes, without reference to any knowledge of related lexical regularities.

Nonetheless, “conspiracies” between phonotactics and alternations pervade the phonologies of the world’s languages. Based on this observation, one might hold that phonotactically-based alternations enjoy a special status, as in the single-mechanism account detailed above. In the realm of acquisition, a resulting prediction is that phonotactic knowledge should aid in the learning of alternations. This is explicitly claimed to be the case in recent L1 learnability work in Optimality Theory (Hayes 2004, Prince and Tesar 2004, Tesar and Prince 2004), in which phonotactic learning precedes, and informs, the learning of alternations.

While much is known about the acquisition of phonotactics, in both perception and production, comparatively little is known about the acquisition of alternations (although see Berko 1958; MacWhinney 1978; Derwing and Baker 1986; Bernhardt & Stemberger 1998; Kerkhoff to appear.) With respect to the current question of their interaction, as far as we know there is no empirical evidence. This lack of empirical results is not surprising, due to the difficulty of finding a testing ground in natural language. It is unlikely that naturalistic language acquisition will ever afford the opportunity to compare the ease of acquisition of two alternations that differ only in whether they are phonotactically motivated.

In this study, we set out to bypass this problem by studying the acquisition of an artificial language. For other applications of artificial language learning to the study of phonological acquisition, see e.g. Esper (1925), Schane *et al.* (1974), Bybee and Newman (1994), Curtin *et al.* (1998), Dell *et al.* (2000), Saffran (2001), Goldrick (2002), and Pater (2003), as well as Nowak *et al.* (2003), Wilson (2003) and Carpenter (to appear), discussed in section 4.

In our study, we compare the learning of two languages: one with a phonotactically motivated alternation, and one with a non-phonotactically motivated alternation. The

phonotactic motivation comes from the native language of the subjects, who were adult native speakers of English. We assume that second language acquisition involves creation of a new grammar, using the same resources as first language acquisition (though other cognitive strategies may be used as well). One major difference, however, is that the initial state of second language acquisition is the final state of first language acquisition, and thus that phonotactic properties of the subjects' native language are available to help in learning the artificial languages. Our research question is thus:

- (9) Does an L1 phonotactic restriction aid in the acquisition of an L2 alternation?

It is worth emphasizing that our assumption about the transfer of L1 phonotactic knowledge into L2 is just that: an assumption. While it is clear that phonotactic restrictions affect L2 learners' productions (for example, in triggering epenthesis in consonant clusters), we cannot be sure that they would transfer at a more abstract level (for example, in phonotactic well-formedness judgments, or in the task below). Therefore, a positive answer to our research question would provide novel evidence of transfer in L2 learning.

2.1. Studying the acquisition of alternations with artificial language learning

The English phonotactic restriction our artificial language exploits is the Minimal Word restriction from (1b): monosyllables that end in a lax vowel are ill-formed (e.g. *[blɛ]). Data from Moreton (1999) provides evidence that English speakers do have productive knowledge of this restriction. In that study, listeners were more likely to identify a vowel that is ambiguous between [ij] and [ɪ] as [ij] in the word-final context than in a context where both are permitted. In addition, Cebrian (2002) shows that native English speakers, and Catalan learners of English, use this restriction in interpreting the morphological composition of nonce words. Since English provides no alternations to repair subminimal words, we thus addressed our research question by asking whether English speakers are able to learn such an alternation more readily than a comparable one without a phonotactic purpose.

Cross-linguistically, alternations can augment sub-minimal words in a variety of ways – for example, by lengthening or epenthesis a vowel (McCarthy & Prince 1991). We chose consonant epenthesis, as in Cupeño (Crowhurst 1994, Lombardi 2003), since vowel lengthening does occur elsewhere in English. The cross-linguistically most common epenthetic consonant is likely to be glottal stop; however because [ʔ] is difficult to perceive, we chose the voiceless alveolar [t] instead, as used in Axininca Campa (Payne 1981, McCarthy and Prince 1993).

Both languages that we constructed contain singular and plural words, in which the plural is marked with the suffix /-so/. In Language 1, epenthesis is used to avoid words that would be sub-minimal in English. It applies to avoid word-final lax vowels, as in the singulars in (10a-c), but not if the singular ends in a tense vowel (10d), or a consonant (10e):

motivation supplied by English. In section 4, we will return to this question of attestedness, and discuss the teasing apart of multiple possible influences on artificial language learning in general.

In terms of Optimality Theory, English-speaking learners of Language 1 will only need to establish a ranking of faithfulness constraints that would choose epenthesis as a repair. The ranking of the relevant markedness constraint(s) (e.g. FOOTBINARITY; Prince and Smolensky 1993) above faithfulness constraints will already be in place, assuming an initial Markedness >> Faithfulness ranking bias that will never have been disturbed because English words do respect the ban on subminimality. On the M >> F learning bias, see especially Smolensky 1996; Hayes 2004; Prince and Tesar 2004; see also Ota 2001 for evidence of child language word minimality effects in Japanese, in which the adult language permits sub-minimal words.

Learners of Language 2 will be faced with a more complex task. The exact nature of that task depends on how “unnatural rules” are learned: as just discussed above, epenthesis following front vowels seems to be unattested cross-linguistically. Under one account (Hayes 1999), they will have to construct a language-specific constraint to drive the alternation, and then fix its ranking with respect to the rest of the hierarchy, as well as establishing the ranking of faithfulness constraints.

3. The experiment

3.1. Materials

Three sets of plural-singular pairs (nonce words in English) were created for each language. In each language, two sets were composed of vowel-final roots, which either induced alternations, or not. For each of the vowel categories (i.e. tense, lax, back, front) there were three vowels, with four instances of each. The other set consisted of consonant-final roots. There were twelve pairs for each set; the following are representative examples:

(14) *Language 1*

<i>V-Final roots (Alternating)</i>	<i>V-Final roots (Non-alternating)</i>	<i>C-Final roots</i>
[kɛso] [ket]	[blejso] [blej]	[tretso] [tret]
[glɪso] [glɪt]	[lijso] [lij]	[vejtso] [vejt]
[yʌso] [yʌt]	[pluwso] [pluw]	[vijkso] [vijk]

(15) *Language 2*

<i>V-Final roots (Alternating)</i>	<i>V-Final roots (Non-alternating)</i>	<i>C-Final roots</i>
[lijso] [lijt]	[vuwso] [vuw]	[ruwkso] [ruwk]
[blejso] [blejt]	[trowso] [trow]	[dijtso] [dijt]
[træso] [træt]	[vaso] [va]	[vijkso] [vijk]

The words were spoken by a trained phonetician in carrier phrases, and edited out for presentation via computer over headphones. Words were paired with picturable nouns (e.g. airplanes/airplane, trees/tree, balls/ball).

3.2. Subjects

Subjects were native speakers of English, with no knowledge of a second language beyond high school level. They were recruited by advertisement and word of mouth, and paid for participation. A between-subjects design was used; each subject learned one of the languages.

3.3. Testing and training

Throughout the experiment, subjects were seated in front of a computer screen, with headphones on. The experiment consisted of three phases, each containing a training block and a testing block with a randomized order of items. In training, plural/singular pairs were presented in turn, by displaying the visual referents on the computer screen and simultaneously playing the aural label over the headphones. Subjects always heard the plural first, and then the singular. Subjects pressed a key to move on to the next pair.

For the testing component, we followed Saffran *et al.* (1996) in using a forced choice task. In each test trial, subjects heard a plural word with its associated plural picture, followed by two possible singular forms of that word with the corresponding singular picture. An example test trial is illustrated in (16):

(16) *Example test trial*

	X	A	B
Audio:	[blejso]	[blej]	[blejt]
Visual:	(picture of apples)	(picture of apple)	(picture of apple)

By pressing a key, subjects had to choose between A and B as singular forms for X. Choices always differed in the presence of the final consonant. For the example in (16), the correct answer for learners of Language 1 would be A, while for Language 2 it would be B.

In each of the first two phases, subjects were first trained and then tested on 9 pairs, with each pair appearing three times in training, and twice in testing. In the third phase, the 18 now-familiar pairs were played once more in training mode for review. Then, subjects were tested on those 18 plus another 18 novel pairs, resulting in 36 total, again with each pair appearing twice.

Thus, subjects were only trained on half of the items, but eventually tested on all of them. The ‘novel’ test items in the third block allowed us to examine whether subjects had acquired the generalization, rather than having simply memorized the correct singulars for each trained plural.

3.4. Results

Data was collected from 29 subjects – 14 in Language 1 and 15 in Language 2. We report the results from only non-outliers (those within two standard deviations of the mean), leaving 11 in Language 1 and 14 in Language 2. Table (17) shows the mean number of correct responses across all subjects in the final testing block, separated into responses for the trained and novel items (standard deviations are given in brackets):

(17) *Performance on all trained and novel items in final test block*

	Language 1 (n=11)	Language 2 (n=14)
<u>Trained items</u>	0.94 (0.05)	0.96 (0.06)
<u>Novel items</u>	0.74 (0.06)	0.66 (0.14)

Both groups did well on the trained items; this may simply indicate that they were able to memorize the correct singular form. However on the novel items, the subjects learning the phonotactically motivated alternation of Language 1 also did better than those in Language 2. A single tailed t-test assuming unequal variance finds the between groups difference on the novel items to be significant ($t(18) = 2.24, p < 0.02$).⁵

These results provide support for the claim that L1 phonotactic knowledge does indeed play a role in the learning of L2 alternations. However, there is a way in which L1 phonotactic knowledge itself could have driven this pattern of results, without any reference to a new L2 phonology. In the Language 1 condition, subjects could have responded correctly to some of the test items merely on the basis of what is phonotactically allowed in English. For example, when faced with [gɛ] and [gɛt] as choices for the singular of [gɛso], the correct response [gɛt] is also the one that is well-formed in English. One might therefore speculate that the two groups did equally well in learning the alternation, but that learners of Language 1 responded correctly more often because they sometimes decided based on what was well-formed in their native language.

Under this alternative explanation, the learners of Language 1 should only outperform Language 2 on the alternating roots – those that trigger epenthesis in the singular. The non-alternating roots should be equally easy or difficult in both language conditions, since their test trials involve a choice between forms that are equally legitimate in English. To test this prediction of the alternative explanation, the following figure graphs the mean proportion correct for each of the two groups for the three root-types (see (14) and (15) for examples of each). Error bars indicate 95% confidence intervals.

⁵ A t-test with all subjects, including outliers, has $p < 0.01$.

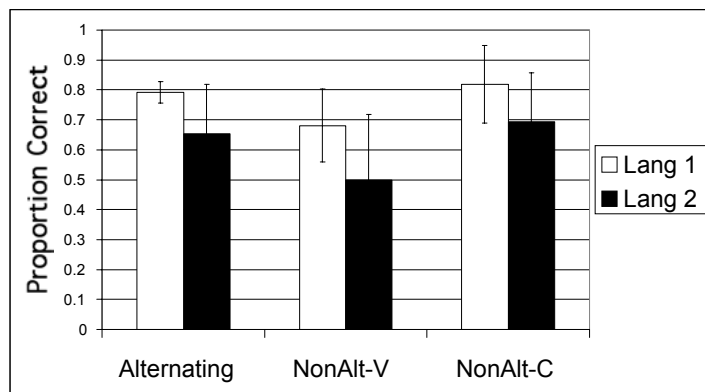


Figure 1. Performance on different root types.

As this graph indicates, subjects learning Language 1 did in fact do better on *all* root types. Poor performance on the non-alternating roots indicates that the learners were incapable of correctly determining the scope of the alternation. It seems that this was more of a problem for learners of Language 2 than Language 1, though this conclusion is still tentative, given that the between group differences within root types do not reach significance.

4. Discussion

Overall, our results indicate that learners do not learn alternations by simply observing the changes to the phonological shape of morphemes, but rather are aided in this task by other aspects of phonological knowledge. This ‘other knowledge’, however, could come from more than one source, whose possibly independent effects we now consider.

4.1. Potential influences on the acquisition of (L2) alternations

Thus far, we have mostly characterized the difference between the two languages in our experiment as a difference in L1 phonotactic motivation: Language 1’s alternation prevents its singulars from violating an English restriction, while Language 2’s alternation has no such explanation. However, it has already been briefly mentioned that our languages also differed in their similarity to the patterns of natural languages: as far as we know, no real language behaves like Language 2 in closing off open front-voweled syllables with an epenthetic consonant. Moreover, we know of no example of a phonotactic constraint which exclusively prohibits open front-voweled syllables, nor of any other alternation that is used to avoid them. Therefore, one alternative explanation for our results is that subjects had trouble with Language 2 because it contained an unattested, or “unnatural”, phonological rule. This alternative explanation rests on the premise that learners can distinguish between possible and impossible rules – a premise that is clearly of no little interest.

Although we do not think that it played a role in our results, another possible influence on the acquisition of an alternation is its formal simplicity. Determining the simplicity of a alternation can depend heavily on theoretical assumptions of how the rules or constraints producing it are formalized, and is thus far from straightforward. However,

as a starting point we can assume that rules that manipulate more features are more complicated (as in Chomsky and Halle's 1968 feature counting metric). As discussed in section 2, we attempted in our experiment to choose two alternations that were as similar as possible – differing only in whether the vowel feature [-tense] or [-back] triggered final [t] epenthesis.

With respect to the L2 acquisition of an alternation, one plausible hypothesis is that all the factors above can ease or inhibit the process. In this view, the spectrum of alternations and their relative learnability could be diagrammed as below (18):

(18) Hypothesized spectrum of factors influencing an alternation's learnability



Because our experiment was designed as an initial foray into the use of an artificial learning methodology for the study of alternations, we designed our materials to provide a clear contrast on the spectrum: pitting Language 1's natural rule with motivation in English phonotactics against Language 2's unnatural rule with no connection to English patterns.

To move on to the more subtle question of how each factor contributes to ease of acquisition, we must test for each factor's influence on learning in turn while keeping other factors constant. Designing such experiments can pose a considerable challenge. To test for phonotactic motivation independent of cross-linguistic attestedness or formal simplicity, one would have to find two nearly identical attested alternations that apply in almost exactly the same environment, and teach them to subjects whose native language provides only the phonotactic motivation for one of them, and not the alternation itself. Testing attestedness as the criterion factor is somewhat easier: this only requires that the nearly-identical rules are unmotivated by L1 phonotactics (though statistical tendencies in the L1 are less easy to control for; C. Wilson, p.c.). Recently, several studies have examined attestedness as a factor (or the related notion of 'naturalness'),⁶ as well as formal simplicity, using artificial language learning paradigms. These studies have all found differences between experimental conditions, which bodes well for the use of artificial language learning in this domain. However, they also highlight the difficulties in teasing apart the factors at play.

Pycha *et al.* (2003) used a similar methodology to ours to compare the acquisition of a suffix whose vowel backness – [u] vs. [ɛ] – was predictable in some way from the root vowel. In their Language 1, the suffix alternated so that it agreed (i.e. assimilated) with the preceding vowel in backness. In Language 2, it consistently disagreed with the preceding

⁶ In general, the terms "natural" and "attested" can both be taken to mean "cross-linguistically attested". However, there are attested phonological alternations that are sometimes categorized as unnatural, because they lack phonetic motivation, have many exceptions, and/or are rare (see esp. Stampe 1969): English velar softening is one example (Pierrehumbert to appear).

vowel in backness (i.e. it dissimilated). In the third language, the suffix was also predictable based on the final vowel, but some stem vowels caused assimilation, and others caused dissimilation. The first two languages were meant to test naturalness as a factor; backness assimilation was labeled as natural due to phonetic factors. However, as Pycha *et al.* note, dissimilation of this type is attested cross-linguistically (in Ainu, Ito 1984 and Yucatec Maya, Kramer 1998), so it is not clear that it is truly unnatural. Therefore, there is little that can be concluded from the fact that no difference was observed between the first two languages. There was a large difference between the success of learners of the third language and the first two. Since the rule for the third language is so complex, Pycha *et al.*'s conclusion that this complexity was the source of difficulty is likely correct, though it is possible that attestedness played a role, since the third language is clearly unattested.

Wilson (2003) also reports an artificial learning study of this type, which did compare an attested and unattested alternation. The two languages he constructed also had an alternating suffix, [-la] vs. [-na], whose shape was predictable in some way from the featural make-up of the preceding stem's final consonant. In the language with an attested pattern, [na] appeared if there was a nasal as the onset of the previous syllable; otherwise the suffix was [la]. The unattested language had the appearance of [na] linked with the presence of a dorsal in the previous syllable. Wilson found that learners of the attested alternation performed much better on a test with novel forms than did the learners of the unattested alternation. He also replicated this result with a dissimilation pattern, which similarly produced better results on the novel word test than did the unattested alternation. However, it is not clear that the processes that are compared in Wilson's study can be considered equivalent in all respects beyond their attestedness. For learners of the nasal assimilation and dissimilation languages, it is only necessary to keep track of the co-occurrence of a single feature: [+/-nasal]. Learners of the random alternation, however, must notice the co-occurrence of [+nasal] or [-nasal] with [dorsal]. This could hamper the learners of the random alternation in two ways. First, they may be less likely to notice the generalization: as a reasonable analogy, a surveyor of passing traffic would more likely notice that every Volkswagen is followed by another VW than notice that every Buick is followed by a VW. Second, they might have more difficulty in formalizing the generalization: assimilation and dissimilation rules are often given a special status, either through use of alpha notation or feature spreading conventions (see Wilson 2003 for discussion of this second alternative). Thus, this study's results do not seem to provide a clear test of acquisition ease as a sole function of attestedness.

Current work in this vein by Carpenter (to appear) provides what seems to be a good test case for attestedness alone. Instead of alternations, her experiment compares two stress rules, both based in part on sonority. The attested rule stresses the leftmost low vowel, and if there are no low vowels, the leftmost high one. The unattested rule is exactly the same, except that it reverses the preference: leftmost high, else leftmost low. Carpenter finds that both English and Québécois French subjects are more successful on a novel word test when they are learning the attested, rather than the unattested language. One potential confound here is that the inherent intensity of low vowels would lead to their being more easily associated with stress; this is the likely source of the cross-linguistic pattern. This

concern is mitigated, however, by the fact that the intensity of the vowels in the experiment was controlled.

These studies provide some indication that cross-linguistic attestedness may influence the acquisition of phonological alternations, though they also highlight the methodological difficulties in addressing these important research questions.

5. Conclusions

Our experimental results indicate that two very similar phonological alternations differ in how easily they are acquired: epenthesis following lax vowels was learned more successfully than epenthesis following front vowels. These alternations differ in whether they are motivated by the phonotactics of the L1, and in whether they reflect cross-linguistically observed phonological patterns. These results could be explained by transfer of L1 phonotactic knowledge into the L2, by access to universal phonological principles, or as we suspect to be accurate, by a combination of the two. Future research should offer insight into the relative contribution of these factors. More generally, we offer this study as a contribution to a line of research that appears very promising: the use of artificial language learning to study otherwise intractable questions in both first and second phonological acquisition.

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