PROJECT MUSE®

The effect of phonotactics on alternation learning

Adam J. Chong

Language, Volume 97, Number 2, June 2021, pp. 213-244 (Article)

Published by Linguistic Society of America
DOI: https://doi.org/10.1353/lan.2021.0017

THE EFFECT OF PHONOTACTICS ON ALTERNATION LEARNING

ADAM J. CHONG
Queen Mary University of London

This study investigates whether alternation learning is facilitated by a matching phonotactic generalization. In a series of artificial grammar learning experiments, English learners were trained on artificial languages evincing categorical vowel harmony alternations across morpheme boundaries. These languages differed in the degree of harmony within stems (disharmonic, semi-harmonic, and harmonic), and thus the degree of phonotactic support for the alternation. Results indicate that alternation learning was best when supported by matching stem phonotactics (harmonic language; experiment 1). Learners, however, were reluctant to extend a learned phonotactic constraint to novel unseen alternations (experiments 2 and 3). Taken together, the results are consistent with the hypothesis that alternation learning is facilitated by a matching static phonotactic generalization, but that learners are conservative in positing alternations in the absence of overt evidence for them.*

Keywords: phonotactics, alternations, derived-environment effects, artificial grammar, phonological learning, vowel harmony

1. INTRODUCTION. It has been observed that similar phonological generalizations often seem to hold both within morphemes and across morpheme boundaries. In the former, these static generalizations govern the distributional cooccurrence of sound sequences in a language (i.e. phonotactics). In the latter, these involve dynamic generalizations where the phonological form of a morpheme changes depending on morphophonological context (i.e. phonological alternations). That these generalizations are often isomorphic was observed by Chomsky and Halle (1968:382): 'in many respects, [lexical redundancy rules] seem to be exactly like ordinary phonological rules, in form and function'. How these generalizations relate to each other in the architecture of the phonological grammar, in acquisition, and over historical time has been subject to longstanding debate.

Within constraint-based phonological models like OPTIMALITY THEORY (Prince & Smolensky 2004 [1993]), these generalizations are generally modeled using a single mechanism (i.e. the same markedness constraint). Because of this close connection, a popular view in phonological learning within these models hypothesizes that the prior learning of phonotactics aids the later learning of alternations (Hayes 2004, Jarosz 2006, Tesar & Prince 2007). Much experimental work in the last decade or so has investigated the factors that facilitate or inhibit the learning of phonological patterns. These studies, though, largely focus on examining the learning of alternations or phonotactics alone. Few studies have directly examined how these different generalizations interact in learning (Pater & Tessier 2005).

Furthermore, there are many patterns in which the isomorphism between static phonotactics and alternations does not hold. One such pattern, derived-environment

---

* This work has benefited from discussion with and feedback from Megha Sundara, Kie Zuraw, Bruce Hayes, Robert Daland, Sharon Peperkamp, Karen Jesney, Stephanie Shih, Sharon Inkelas, Ricardo Bermúdez-Otero, Jamie White, and the audiences at the University of Melbourne, UCLA, the University of Hawai'i, NYU, QMUL, the University of Manchester, the Keio-ICU Colloquium, and LSA 2017 in Austin. I would also like to thank Eleanor Glewwe for recording stimuli, Audrey Kim for helping with the initial piloting of the experiment, and Michael Becker (Stony Brook) and Daniel Szeredi for assistance with Experigen. This work was funded by a UCLA Dissertation Year Fellowship and appeared as a chapter in the author's 2017 UCLA dissertation (Chong 2017). The study protocol was certified exempt by the UCLA Institutional Review Board: IRB#15-000223.

effects (Kiparsky 1993), involves alternations that go against morpheme-internal phonotactics. Such patterns have long posed a challenge for phonological theories (for a recent review, see Inkelas 2015). In a model in which phonotactics and alternations are closely linked, these types of patterns are predicted to be harder to learn, relative to patterns in which both generalizations match. This is not predicted by models that do not posit such a link.

In this article, I examine precisely this link between phonotactic and alternation learning in a series of artificial grammar learning experiments. I compare, specifically, the learning of phonological patterns that evince a derived-environment effect compared to one that does not. I further examine whether learners are biased to extend static phonotactic patterns to novel alternations. The results show that the learning of static phonotactic patterns and the learning of alternations are linked, although learners do not readily generalize learned phonotactics to novel alternations in the absence of evidence for the alternation. These findings have implications for a model of phonological learning, as well as for the learnability of derived-environment effects, an underexamined aspect of these patterns.

In the rest of this section, I first discuss the relationship between phonotactics and alternations, how these are modeled, and the existing literature on phonotactics and alternations in acquisition, before introducing the current set of experiments.

1.1. The relationship between phonotactics and alternations. An example of the isomorphism between static phonotactic generalizations and active alternations can be seen in Navajo sibilant harmony. In Navajo, all sibilants in a root must agree in their [anterior] feature (Sapir & Hoijer 1967, Kari 1976, McDonough 1991, 2003, Fountain 1998). The tautomorphemic harmony restrictions mean that only harmonic roots like those in 1 exist, while the hypothetical disharmonic Navajo roots in 2 are not attested (all data cited here are reproduced from Martin 2011:753, originally from Fountain 1998).

(1) Navajo: harmonic roots
 a. [**tʃ’**o**ʒ**] ‘worm’ ([−anterior]…[−anterior])
 b. [**ts’**ó**z**í] ‘slender’ ([+anterior]…[+anterior])
(2) Hypothetical (unattested) disharmonic roots
 a. *[**s**o**ʃ**] (*[+anterior]…[−anterior])
 b. *[**tʃ**i**z**] (*[−anterior]…[+anterior])

This cooccurrence restriction also holds across morpheme boundaries, as in 3, with the prefix sibilant typically harmonizing with the [anterior] feature of the root sibilant. In 3a, the prefix /-s-/ harmonizes to the root sibilant [ʒ], surfacing as [ʃ]. In 3b, by contrast, the prefix and root sibilants agree in anteriority, and thus the prefix sibilant does not show alternation.

(3) Navajo harmony: prefix+root
 a. /ji-**s**-léé**ʒ**/ → [ji-**ʃ**-léé**ʒ**] ‘it was painted’
 b. /ji-**s**-ti**z**/ → [ji-**s**-ti**z**] ‘it was spun’

In a rule-based (SPE: Chomsky & Halle 1968) account, the generalization that stems show sibilant harmony would have been accounted for via context-free morpheme structure rules or constraints (MSRs, or MSCs). The generalizations across morpheme boundaries, by contrast, were captured by regular phonological rules. MSCs applied directly in the lexicon prior to the application of any phonological rules. Crucially, MSCs and regular phonological rules were totally distinct from each other with no linking mechanism, even though they often achieved the same end. This ‘duplication problem’ (Kenstowicz & Kisseberth 1977) was one motivation that led to the shift to optimality theory (OT; Prince & Smolensky 2004 [1993]), which unified the explanatory burden for both static phonotactic patterns and active phonological alternations into a single mechanism (i.e. markedness constraints).

Not everyone agrees that the duplication problem is an issue (e.g. Anderson 1974, Paster 2013). Paster (2013), for example, argues that this is only an issue if we assume two things: (i) that static generalizations are psychologically real and must therefore be encoded in a grammar, and (ii) that ‘the functional unity of two or more phenomena observed in a language should correspond to unity of formal explanation for the phenomena’ (Paster 2013:82). Paster argues that if language change in OT involves constraint reranking, and a single constraint allows you to capture both static and active generalizations, then both static patterns and active processes should undergo changes in tandem.

Indeed, static phonotactic patterns and phonological alternations can, and do, pull apart historically, arguing potentially for their independence (see Paster 2013 for a summary). On the one hand, it is common to find cases of morpheme-internal phonotactic patterns that do not engender any phonological alternations across a morpheme boundary (e.g. Chomsky & Halle 1968). Nonlocal laryngeal cooccurrence restrictions often fall into this class of patterns (e.g. MacEachern 1997). For example, in Bolivian Aymara (data from MacEachern 1997 and Gallagher, Gouskova, & Camacho Rios 2019), nonidentical ejectives cannot cooccur within a morpheme (4), but they can cooccur across morpheme boundaries within the same word (5).

(4) Bolivian Aymara: phonotactic restrictions within morphemes
  a. [**k’**as**k’**a] ‘acid to taste’
  b. [**t’**an**t’**a] ‘bread’
  c. *[**t’**an**k’**a] (hypothetical (unattested) root)
(5) No restrictions across morpheme boundaries within the same word
  a. [**ʧ’**um-**t’**a-ɲa] ‘about to drain’
  b. [**t’**isn-**ʧ’**uki-ɲa] ‘to thread carefully’

On the other hand, the reverse patterns are also found, notably patterns that are classically described as nonderived environment blocking (NDEB) or derived-environment effects (DEEs; I refer to these as DEEs in this article). A well-known example is palatalization in Korean (Iverson & Wheeler 1988, Kiparsky 1993, Oh 1995, Cho 2001). Across a morpheme boundary, underlying /t, t^h/ palatalize to [c, c^h] before /i/ and /j/, as seen in 6. However, analogous monomorphemic forms in 7 do not palatalize. Here, there is a mismatch between tautomorphemic static generalizations (e.g. [ti] is allowed) and the heteromorphemic dynamic generalization (e.g. [t-i] is repaired by palatalization). Patterns such as these have often required additional theoretical machinery to be accounted for in OT (e.g. indexed constraints, Pater 2007; interleaving of morphology and phonology, Wolf 2008; underspecification, Kiparsky 1993, Inkelas 2015). I return to these DEE patterns in §2 below in the context of the current study.

(6) Korean: derived palatalization
  a. /mat-i/ → [maci] ‘eldest.NOM’[1]
  b. /pat^h-i/ → [pac^{h}i] ‘field.NOM’
(7) Nonderived blocking of palatalization
  a. /mati/ → [mati] ‘knot, field’
  b. /titi-ta/ → [titita] ‘to tread’

---

[1] NOM: nominative, GEN: genitive, SG: singular, PL: plural.

At the same time, while these patterns clearly show a dissociation between phonotactics and alternations, there is also evidence that phonotactic constraints within a morpheme or word can exert some influence on generalizations over larger domains. Martin (2011), for example, shows that in the Navajo sibilant harmony case in 1 and 3 above, the harmony generalization within a word also extends to compound formation, albeit to a lesser degree. In fact, phonotactic effects have been shown to also trickle up to the level of sentence formation (Shih & Zuraw 2017, Breiss & Hayes 2020). These patterns suggest then a possible bias to have similar generalizations across multiple domains.

Computational models of phonological learning within constraint-based frameworks often rely on this close relationship between phonotactic generalizations and alternations described above. In common among these models is the idea that morphologically blind phonotactic learning occurs prior to alternation learning, since all that is needed for this stage is surface distributional evidence (Hayes 2004, Jarosz 2006, Tesar & Prince 2007). Adriaans and Kager (2010), for example, present a computational model of acquisition that is able to induce phonotactics from unsegmented speech (i.e. without lexical information). Alternation learning is delayed, however, since it requires the prior learning of a lexicon and morphological paradigms in order to track the mapping between different input-output forms. The timeline in infant development of these two types of phonological knowledge offers some support for the hypothesis that phonotactic knowledge is in place before knowledge about alternations. By eight to ten months of age, infants show preferences for phonotactically legal structures over illegal ones in their native language (e.g. Friederici & Wessels 1993, Jusczyk et al. 1994, Saffran & Thiessen 2003). But the development of alternation knowledge in production, however, seems more protracted, going beyond the second year of life (e.g. Zamuner, Kerkhoff, & Fikkert 2012).

To the extent that perception precedes production, however, evidence from word-recognition studies shows that toddlers are able to successfully recognize words that show alternations between eighteen and twenty-four months (Skoruppa et al. 2013, Chong & Sundara 2015). Further evidence for the emergence of the mechanism to learn alternations has been shown to be in place even earlier. White et al. (2008) showed that infants at twelve months were able to learn a novel alternation using distributional cues for the input. They further found that while 8.5-month-old infants were able to learn the frequency of sound sequences in the input, they did not show any evidence of grouping alternating sounds into one functional category (i.e. linking them to the same abstract form). More recent evidence by Sundara et al. (2021) documents the trajectory of learning of an English alternation (/d/-tapping) at twelve months, but not at eight months. All in all, these studies suggest that phonotactic knowledge seems to emerge earlier than alternation knowledge.

In most constraint-based models, it is often assumed that the later alternation learning is significantly aided by this first stage of phonotactic learning. This follows if alternations and phonotactics are encoded by a single mechanism—that is, the same markedness constraints. The idea is that phonotactic learning primarily involves learning what the legal surface structures are and that these are encoded with markedness constraints, either with a bias toward higher ranking of markedness constraints over faithfulness (e.g. Hayes 2004, Tesar & Prince 2007) or in a model that only deals with learning markedness constraints from surface forms (e.g. Hayes & Wilson 2008). Once phonotactic knowledge (i.e. the relative importance of markedness constraints) is learned, then children's subsequent learning task dealing with alternations is significantly simplified since they can concentrate on learning the relevant repair to 'fix' illicit structures

(Hayes 2004, Jarosz 2006, Tesar & Prince 2007) that they have already learned to flag from earlier phonotactic learning. Jarosz (2011), for example, shows that a computational learning model with early phonotactic learning mirrors closely the findings in L1 acquisition of Dutch voicing alternations (Zamuner et al. 2012).

These models that posit a single mechanism contrast with grammatical models that do not posit any link between phonotactics (or MSCs) and alternations (e.g. rule-based SPE; see also Rasin 2016 for a recent proposal in a similar vein). Certainly, the fact that these generalizations can pull apart historically (see above and Paster 2013 for a summary) is suggestive that these generalizations are likely not entirely isomorphic. Some have gone further in eschewing the explanatory status of static distributional patterns entirely. For example, Hale and Reiss (2008) argue that MSCs are not part of a speakers' grammatical knowledge and are computationally inert with regard to input-output mappings that the grammar governs. Note that the choice of constraints vs. rules is not in principle crucial here, but rather whether one component (alternations) has access to the other (phonotactics). For example, Albright and Hayes's (2003) rule-based morphophonological alternation learning model relies significantly on existing phonotactic knowledge.

These two classes of models therefore make different predictions for alternation learning depending on the kind of phonotactic evidence available. In particular, they make different predictions for the learnability of patterns in which phonotactics and alternations mismatch. On the one hand, models such as OT, in which phonotactics and alternations are encoded using a single mechanism, predict that alternation learning should be more difficult if the phonotactics do not support the alternation. Models in which no such link is explicitly built in, or which eschew any explanatory role for static phonotactic generalizations, predict that there should be no difference in alternation learning as a function of phonotactics. These models do not privilege supporting phonotactics, nor do they predict any interaction between both types of generalizations in learning—both of these generalizations are predicted to be learned independently. In this article, I examine precisely these predictions using an artificial grammar learning study. In the next sections, I first review previous experimental investigations of phonotactic and alternation learning, before turning to the specific aims of the current study.

1.2. PREVIOUS EXPERIMENTAL INVESTIGATIONS. A growing body of work in the last decade or so has examined what mechanisms are involved in phonotactic and alternation learning using artificial grammar learning experiments with adults (e.g. Pycha et al. 2003, Wilson 2006, Moreton 2008, Finley & Badecker 2009, 2012, White 2014) and infants (e.g. Cristià & Seidl 2008, White et al. 2008, White & Sundara 2014). Typically, experimental studies on phonological learning using artificial grammar learning have primarily focused on either the learning of phonotactic knowledge alone (e.g. Onishi, Chambers, & Fisher 2002, Chambers et al. 2003, Saffran & Thiessen 2003, Richtsmeier 2011, Skoruppa & Peperkamp 2011, Linzen & Gallagher 2017) or the learning of phonological alternations alone (e.g. Wilson 2006, Kapatsinski 2010, Cristià et al. 2013, White 2014).

Few studies have examined how these two types of generalizations interact in learning. Providing some support for the facilitative nature of phonotactic learning, Kapatsinski (2013, 2017) showed that training participants on an overrepresentation of plural forms with particular structures (e.g. [t͡ʃ-i]) results in learners producing alternations resulting in those structures, even if the alternation (e.g. /t-i/ → [t͡ʃ-i]) is not experienced in training. Pater and Tessier (2005) provided further support for the facilitative role of phonotactics in alternation learning. American English speakers were trained in their study on an alternation ([t]-epenthesis) that was motivated by either a phonotactic generalization in English (lax vowels do not occur in final open syllables (Moreton 1999), e.g. /blɪ/ → [blɪt] but /bli/ → [bli]) or one not supported in the English lexicon (front vowels do not occur in final open syllables, e.g. /li/ → [lit] but /fu/ → [fu]). Conforming to Pater and Tessier's (2005) prediction, learners learned the alternation better in the language with phonotactic support from learners' L1 English ([t]-epenthesis following lax vowels) than the one without ([t]-epenthesis following front vowels). However, the authors point out that, while both languages are of equivalent formal complexity, the latter is typologically unnatural and unattested. Given that previous studies have shown that learners show a dispreference against unnatural patterns (Hayes et al. 2009, Becker, Ketrez, & Nevins 2011, Hayes & White 2013), it is therefore possible that the poorer performance in the language without phonotactic support could be explained by this alone.

More recent investigations have also failed to find conclusive evidence for a link between phonotactics and alternations. In Chong 2016, participants were trained on two artificial languages in which coronal stops (/t/ and /d/) palatalized to [t͡ʃ] and [d͡ʒ] across a morpheme boundary before /i/ (e.g. /dat-i/ → [dat͡ʃ-i] and /dubad-i/ → [dubad͡ʒ-i]). In the across-the-board language, [ti]/[di] sequences did not appear within stems (e.g. stems like [t͡ʃid] are attested, but not [tib]), ensuring a match between stem phonotactics and alternations (both conform to a constraint *[ti]/[di]). The other language evinced a DEE modeled on the pattern in Korean described above in 6 and 7: [ti] and [di] sequences appeared within stems mismatching with the alternation (e.g. both [t͡ʃid] and [tib] are attested, even though the latter sequence is palatalized across a morpheme boundary). Participants in both languages learned the palatalization alternation equally well. However, it was unclear what kind of phonotactic generalizations were learned in both languages. Learners in the across-the-board language did not show a difference in endorsement rates of stem-internal [ti]/[di] (e.g. [tibut]) compared to phonotactically legal filler items (e.g. [dakat]) in a blick test (Scholes 1966), despite an absence of [ti]/[di] sequences in training. It was, therefore, unclear whether learners in this language learned a phonotactic constraint against [ti]/[di] sequences as intended. Learners in the derived-environment language showed a similar pattern, though interestingly endorsed [ti]/[di] stems like [tibut] more often than learners in the across-the-board language did. Thus, because it was unclear what phonotactic generalizations, if any, were learned, the results of that experiment were inconclusive vis-à-vis the question of whether phonotactics and alternations are linked in learning.

In another study, Pizzo (2015) examined the degree to which alternation learning affected the learning of phonotactics. Participants in this study were trained on one of two alternations involving consonant clusters across morpheme boundaries: obstruent voicing assimilation (e.g. *nema**b**-fa* → *nema**p**fa*), in which an obstruent devoices preceding another voiceless obstruent, or place assimilation (e.g. *lobo**n**-fa* → *lobo**m**fa*), in which nasals assimilate in place to the following obstruent. Because this was a poverty-of-stimulus design, in the training data, stems did not contain any consonant clusters that would have provided static evidence in support of either alternation (i.e. stems like *teldus* are attested with a cluster but not analogous ones like **tepfus*, which would provide static support for the voicing assimilation constraint). Thus, the evidence in the lexicon was ambiguous as to the nature of the phonotactic generalization. In the test phase, participants were given a pair of novel stems with stem-internal consonant clusters and had to decide which word belonged to the language they had just learned (e.g.

voicing assimilation: *madfas* vs. *matfas*). For example, if participants were trained on voicing assimilation, when faced with a pair like *madfas* vs. *matfas*, they should prefer the latter since this conforms to the alternation pattern, thus extending the alternation pattern to static phonotactics. Participants showed significant generalization from alternations to phonotactics only when there was an intermediate feedback stage in which participants were tested on the alternation they were trained on and provided with corrective feedback. Participants had to reach an accuracy criterion for selecting the correct plural (e.g. the correct plural for *nema**b*** is *nema**pf**a*, not *nema**bf**a*) before they were able to proceed to the final test phase. Pizzo argued that it was possible that participants' attention was drawn to the relevant constraint through feedback, thereby explaining their success in generalizing the learned alternation to phonotactics. When this feedback stage was absent, however, Pizzo found no clear effect, although there was a numerical trend in the predicted direction.

Taken together, previous experimental investigations provide inconclusive empirical evidence for the relation between the learning of phonotactics and the learning of alternations (in either direction), due to either experimental confounds or inconclusive results. The current study is therefore designed to examine this link, while seeking to avoid some of the confounds and issues of previous studies. In the next section, I give a general overview of the experiments and preview the results.

1.3. CURRENT STUDY. In the series of the experiments described below, I examine how phonotactics and alternations interact in learning using an artificial grammar learning paradigm. To do so, I compare the learning of alternations between languages that differ in terms of whether there is a supporting phonotactic generalization within stems (experiment 1). Specifically, I consider what impact mismatched stem-internal phonotactic patterns have on the learning of a related phonological alternation, a pattern modeled after DEEs described in §1.1. DEEs are a particularly useful pattern for testing the impact of static stem phonotactic patterns on alternation learning, since we are able to keep the alternation pattern constant while varying the phonotactic evidence. If phonotactics and alternations are learned through a shared mechanism, we expect alternation learning to be less accurate in the cases where there is a mismatch between the stem phonotactics and the generalization that drives the alternation. Experiments 2 and 3 further probe this link between phonotactics and alternations by examining whether learners generalize a learned phonotactic generalization to an unseen alternation, simulating the possible trajectory in L1 acquisition.

To briefly preview the results, learners fail to learn alternations when they are not supported by stem phonotactics (experiment 1), and they do not readily generalize a learned static generalization to an unseen novel alternation (experiments 2 and 3). These results support a model of the grammar and of learning in which phonotactics and alternations are linked, but in which learning is conservative, with an initial anti-alternation bias. That is, learners do not readily assume alternations in the absence of evidence for them. The findings also provide the first empirical evidence that, all else being equal, alternations in DEE patterns are harder to learn. Thus, they also provide an insight into the learnability of DEE patterns, an as yet underexamined aspect to these patterns.

2. EXPERIMENT 1. Experiment 1 was designed to compare alternation learning when there is a match or mismatch with phonotactic generalizations within stems using a vowel harmony pattern. The choice of vowel harmony in these artificial languages was motivated by a few factors. First, it is not a phonological pattern active in English, so we can control for first language phonotactic knowledge. Moreover, previous studies using artificial grammar learning experiments have shown that learners, with a short amount of exposure, are able to learn vowel harmony and generalize to unseen words (Pycha et al. 2003, Koo & Cole 2006, Finley & Badecker 2009, 2012). Pycha et al. (2003), for example, trained participants on singular ~ plural pairs like [gip] ~ [gip-ɛk] or [sun] ~ [sun-ʌk], involving backness vowel harmony between the suffix and stem vowel. Participants in their study successfully learned the harmony pattern and were able to generalize this to unseen novel forms in a forced-choice task.

Importantly, Skoruppa and Peperkamp (2011) showed that participants are able to successfully learn a static phonotactic generalization regarding well-formedness of words with relatively short exposure (see also Moreton 2008). In their experiment, French listeners were trained on passages in two made-up versions of French that involved either vowel rounding harmony or disharmony (e.g. Harmonic French contained pseudowords like *liquère* [likɛʁ], in which both front vowels agree in rounding, vs. *liqueur* [likœʁ] in Standard French, where the front vowels disagree in rounding). Participants were then presented with harmonic and disharmonic nonword pairs (e.g. harmonic *liquère* [likɛʁ] vs. disharmonic *pudère* [pydeʁ]) in a forced-choice task and asked which form belonged to the accent they were exposed to. Participants exposed to the Harmonic language showed a significant preference for harmonic nonwords over disharmonic nonwords, indicating successful learning of a static phonotactic generalization.

Finally, vowel harmony patterns are often involved in DEE patterns in which there is a mismatch between stem phonotactics and alternations, and these patterns occur naturally across the world's languages, as described in §1.1. Turkish, for example, shows a vowel harmony alternation across a morpheme boundary, where the suffix vowel alternates to agree in backness with the final vowel of the root (Lewis 1967, Clements & Sezer 1982), as shown in 8, although roots themselves can be either harmonic or disharmonic, as seen in 9. In disharmonic roots (8e–g), the suffix vowel agrees with the backness of the final vowel of the root.

(8) Turkish vowel harmony across morpheme boundaries ((a)–(d) are from Clements & Sezer 1982:216; (e)–(g) are from Gorman 2013, originally from TELL: Inkelas et al. 2001)

a.	/ip-lAr/[2]	→	[ip-ler]	'rope-NOM.PL'
b.	/sap-lAr/	→	[sap-lar]	'stalk-NOM.PL'
c.	/son-In/[3]	→	[son-un]	'village-GEN.SG'
d.	/jyz-In/	→	[jyz-yn]	'face-GEN.SG'
e.	/mezar-lAr/	→	[mezar-lar]	'grave-NOM.PL'
f.	/model-lAr/	→	[model-lar]	'model-NOM.PL'
g.	/sabun-lAr/	→	[sabun-lar]	'soap-NOM.PL'

(9) Turkish vowel harmony (a–b) and disharmony (c–d) in stems (data from Crothers & Shibatani 1980:64)

a.	[sekiz]	'eight'	(harmonic)
b.	[oda]	'room'	(harmonic)
c.	[mezat]	'auction'	(disharmonic)
d.	[kitap]	'book'	(disharmonic)

Vowel harmony thus not only is learnable in a laboratory setting in terms of both active phonological alternations and static phonotactic generalizations, but it is also a pattern implicated crosslinguistically in mismatches between both of these generalizations. This is therefore a useful pattern that allows us to examine how alternations and phonotactic learning interact.

---

[2] Uppercase letters indicate vowels in the suffix that harmonize to the vowel in the root.

[3] The surface form of the vowel 'I' in the suffix is derived by both rounding and backness harmony.

Participants in this experiment were randomly assigned to one of three artificial languages involving vowel harmony: Harmonic, Semiharmonic, and Disharmonic. In all three languages, there was an exceptionless harmony alternation pattern in which the vowel in the plural suffix [-mu] ~ [-mi] alternated to agree in backness with the final vowel of the singular stem. Participants in all three languages were therefore trained on the same amount of evidence for the same categorical alternation with similar phonological conditioning (cf. Pater & Tessier 2005). Where the languages differed was in how much stem phonotactic support there was for the alternation. In the Harmonic language, vowels in all stems always agreed in backness (e.g. [ˈpime] but *[ˈpimo]), supporting the alternation pattern across the morpheme boundary. In the Disharmonic language, vowels in half of the stems agreed in backness (e.g. [ˈpime]), whereas the other half did not (e.g. [ˈpimo]), resulting in a mismatch between the alternation pattern and stem phonotactics. In the Semiharmonic language, vowels in three fourths of the stems agreed in backness whereas one fourth did not, resulting in partial stem-internal phonotactic support for the alternation.

Since we are interested here in knowledge of both static phonotactic patterns and alternations, participants' knowledge was probed in two separate test phases designed to examine each of these separately. Participants' knowledge of stem phonotactics was examined using a two-alternative forced-choice task in the first test phase, following Skoruppa and Peperkamp (2011). This test phase involved no accompanying semantic information (by way of images). For convenience, this phase is referred to as the 'blick test' (Scholes 1966). Participants' knowledge of the phonological alternation was examined using a different forced-choice task involving singular-plural images. Participants had to pick the correct plural form based on two possibilities. This task is often used in artificial language experiments examining alternation learning (e.g. Coetzee 2009, Finley & Badecker 2009, White 2014, Martin & White 2021). For convenience, this phase is referred to as the 'wug test' (Berko 1958). If alternations and phonotactics are linked in learning, we expect that learning overall will be more accurate in the Harmonic language than in either the Semiharmonic or the Disharmonic language. I return to specific predictions below in §2.2.

2.1. METHODS.

PARTICIPANTS. A total of forty-five American English participants (fourteen male, thirty female, one unreported; mean age: twenty-two) were recruited from the UCLA Psychology Pool, and all participated for course credit. Participants were randomly put into one of the three artificial language groups (fifteen in each). Twenty-five more were tested but were excluded due to having the wrong first language background (n = 4), knowing a language with vowel harmony (Armenian; n = 1), not completing the experiment (n = 15), recognizing the vowel harmony pattern (n = 2), or taking notes (n = 3). These exclusions were based on a post-experiment online debriefing form that participants had to fill in.

PROCEDURE. Participants were tested over the Internet using Experigen (Becker & Levine 2014) and were told that they were going to learn words from a foreign language. They were asked to pay attention to what they were hearing but were told that they did not have to memorize any of the words. On each trial in the training phase, either singular or plural word forms were presented auditorily, accompanied by a corresponding image. That is, singular and plural word forms were not presented side by side on the same trial. This meant that learners were not able to directly compare singular and plural forms on a given trial, but had to do so across trials, making it a more difficult learning task. There were three training blocks with sixty-four trials each, resulting in a total of 192 training trials. On a given trial, participants were able to hear a particular stimulus item just once (i.e. they could not replay stimulus items).

In the first test phase—the blick test—participants heard two novel CVCV words (one harmonic and one disharmonic, e.g. [ˈgike] and [ˈgiko]) and had to decide which belonged to the language they had learned. These were all ostensibly singular stems as they were all disyllabic. No images were presented during this phase in order to encourage decisions based on just the phonological form. The order of presentation of the two CVCV options was randomized such that harmonic words and disharmonic words occurred equally as often as the first member of the pair.

Finally, in the wug test phase, participants heard a novel CVCV singular stem with an accompanying singular image (e.g. one frog), then saw a plural image (e.g. two frogs) and heard two possible forms for the plural ([-mi] vs. [-mu]) for that plural image. They then had to pick what they thought was the correct plural form. This differs from the blick test phase in that participants are given the paradigmatic information between singular and plural pairs with accompanying images. Thus, while the contrast in the blick test was between possible singular stems, in the wug test the contrast was between forms that showed harmonizing and nonharmonizing suffixes. The order of presentation of each possible plural form was counterbalanced such that each plural form occurred equally as often as the first member of the pair.

Artificial languages. Three artificial languages were constructed that consisted of disyllabic CVCV singular stems, along the lines of the artificial languages in Finley & Badecker 2009. CVCV singular stems were constructed using the consonants {p, b, t, d, k, g, m, n} and the vowels {i, e, u, o}. The plural was marked with a suffix that had two allomorphs, [-mu] or [-mi], which agreed with the backness/roundness specification of the final vowel of the stem. The allomorph [-mu] appeared when the final vowel of the root was back/rounded [u, o], and the allomorph [-mi] appeared when the final vowel of the root was front/unrounded [i, e]. Across all three languages, the plural suffix always harmonized with the final vowel of the stem, with stems occurring equally frequently with the [-mu] allomorph and the [-mi] allomorph (half each). All three languages, therefore, had the same amount of evidence for the same alternation (100%).

Where the languages differed was in the proportion of harmonic stems in training. In the Harmonic language, all singular stems contained vowels that were harmonic for backness/roundness (e.g. [ˈbuno] but *[ˈpume]). All harmonic V-V sequences occurred equally frequently. By contrast, in the Disharmonic language, half of the stems contained harmonic vowel sequences (e.g. [ˈbuno]) and half disharmonic (e.g. [ˈpume]), yielding a mismatch between phonotactics and alternations. All V-V sequences, both harmonic and disharmonic, occurred equally frequently. This means that the total number of harmonic V-V sequences was half that in the Harmonic language. Finally, in the Semiharmonic language, 75% of the stems contained harmonic vowel sequences, with the remaining quarter of the stems containing disharmonic vowel sequences. Each possible disharmonic V-V sequence occurred just once. Disharmonic stems were created by changing one of the vowels in a harmonic stem, thereby ensuring that as much as possible was kept constant across all of the languages. In total, thirty-two CVCV stems were created for each language. A summary of the proportion of harmonic and disharmonic stems across all three languages is shown in Table 1, and a full list of training items can be found in the appendix (Tables A1–A3).

For the blick test, sixteen pairs of novel test words were created using the same set of consonants and vowels as the training stimuli. Each pair of blick test words contained a harmonic word (e.g. [ˈgike]) and a disharmonic word (e.g. [ˈgiko]). Disharmonic words

LANGUAGE	DISHARMONIC	SEMIHARMONIC	HARMONIC
	ALTERNATION (ACROSS MORPHEME BOUNDARY)		
Rate of HARMONY alternation	32 (100%)	32 (100%)	32 (100%)
	STEM PHONOTACTICS		
# (and %) of HARMONIC stems (e.g. [buno])	16 (50%)	24 (75%)	32 (100%)
# (and %) of DISHARMONIC stems (e.g. [pume])	16 (50%)	8 (25%)	0 (0%)
EXAMPLE PLURALS	[buno-mu] [pume-mi]	[buno-mu] [pume-mi]	[buno-mu] *[pume-mi]

TABLE 1. Summary of artificial languages. * indicates that these forms are unattested in the artificial language.

were created by changing one vowel's backness (and roundness) specification, while maintaining the same height feature. Half of the blick items differed in the first vowel, and the other half in the second vowel. Finally, for the wug test, sixteen novel disyllabic words were created in the same fashion, except that only harmonic stems were used. The same novel test stimuli in both blick and wug tests were used with learners in all three language groups. Note that in the blick test, it is only in the Harmonic language that there is always a correct answer—the harmonic word. Either word is possible in the Semiharmonic and Disharmonic languages. Contrastively, in the wug test, there is always the same correct response (i.e. the harmonizing plural) across all three languages. A full list of test stimuli is given in the appendix (Tables A6–A7).

AUDIO STIMULI. Audio stimuli were recorded by a female, phonetically trained speaker of American English who was naive to the goal of the current study. Target words were always realized with declarative intonation, with stress placed on the initial syllable of the target word, ensuring that stress was always on the same syllable in both singular and plural forms. Voiceless stops were always produced with aspiration, and voiced stops were produced with voicing through the entire closure as much as possible. Recordings were made using PCQuirer (Scicon R&D 2015) at a sampling rate of 22,050 Hz and were scaled to an average of 70 dB.

VISUAL STIMULI. Visual stimuli consisted of digital images of animals and everyday objects obtained freely over the Internet (260 × 200 pixels). Singular images always contained just one animal/object, and plural images always contained two.

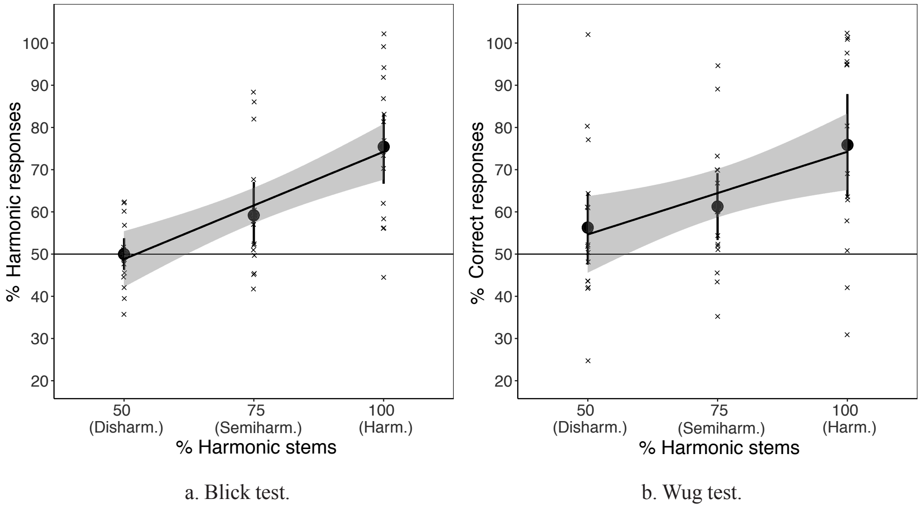
2.2. PREDICTIONS FOR LEARNING. Based on Moreton's (2008) and Skoruppa and Peperkamp's (2011) findings, we expect Harmonic language learners to learn the phonotactic pattern successfully. Because there is no such generalization available for Disharmonic language learners, they should not infer any phonotactic generalizations regarding harmony. Finally, in the Semiharmonic language, we expect the learning of the phonotactic constraint to be better than in the Disharmonic language group, but worse than in the Harmonic language group, given that learners are sensitive to gradient statistical generalizations in their input language (e.g. Hayes 2000, Frisch & Zawaydeh 2001, Goldrick & Larson 2008, Hayes et al. 2009, Becker et al. 2011).

Recall that in all three languages, there was exceptionless evidence for the phonological alternation across the morpheme boundary. That is, the phonological conditioning for the choice of allomorph for the plural was consistent across all three languages. So, unlike in the blick test, the correct response was always the harmonic plural in all three languages: for example, for a singular like [ˈkobo], the correct plural would be [ˈkobomu] and not *[ˈkobomi]. Moreover, all stems in the wug test were harmonic, thus grammatical in all three languages. If phonotactics has no impact on alternation learning, we expect that learners in all three language groups should learn the alternation equally well.

If, however, phonotactics has an effect on alternation learning, we expect the strength of alternation learning to mirror that of phonotactic learning: Harmonic language learners will learn the alternation the best, Disharmonic learners the worst, and Semiharmonic language learners in between. Importantly, we expect that the Disharmonic learners, in particular, will be poorer at learning the alternation despite the exceptionless evidence for it in training.

2.3. RESULTS.

BLICK TEST: PHONOTACTIC GENERALIZATIONS. Figure 1a shows the rate of choosing harmonic words in the blick test across the three language groups. First, I was interested in whether, on the whole, there was a significant relationship between the PROPORTION of harmonic stems in training and the rate of choosing harmonic stems. A mixed-effects logistic regression model (Jaeger 2008), using the 'glmer' function from the 'lme4' package (Bates et al. 2015) in R (R Core Team 2015), was fit to the blick data, with proportion of harmonic stems in training as a continuous variable. The model also contained by-subject and by-item random intercepts. This was the maximal model to converge. Full model specifications for all models are provided in the supplementary materials.[4] Significance values were obtained using the 'summary()' function. The rate of choosing harmonic words increased significantly as a function of the proportion of harmonic stems in the training language ($\beta = 0.024$, $SE = 0.005$, $z = 4.73$, $p < 0.001$). That is, the higher the proportion of harmonic stems in the trained language, the more likely learners were to choose harmonic words over disharmonic words in the blick test.



a. Blick test.

b. Wug test.

FIGURE 1. Experiment 1: Rate of choosing harmonic words in the (a) blick test and (b) wug test. Each black cross represents a single participant, with the large black dot indicating mean rates for each language group with 95% confidence intervals. The linear black line indicates a linear fit to the data, with 95% confidence intervals in gray shading.

---

[4] The supplementary materials can be accessed online at http://muse.jhu.edu/resolve/121.

Next, I analyzed the rate of choosing harmonic words with Language (Harmonic, Disharmonic, and Semiharmonic) as a categorical factor in order to directly compare performance between each language group. The model also contained by-subject and by-item random intercepts. This was the maximal model to converge. I was interested in (i) whether participants' performance in each language group was significantly different from chance (i.e. is the intercept significant?), and (ii) how the rate of choosing harmonic words differed between each language group. Significance of the fixed factor was initially assessed using the summary() function. Post-hoc simultaneous multiple comparisons were then conducted using the 'multcomp' package (Hothorn, Bretz, & Westfall 2008) in R using a contrast matrix (see supplementary materials) to ascertain whether each language differed significantly from chance, and how each language differed from each of the others. *P*-values were adjusted using Shaffer's correction for multiple comparisons (Shaffer 1995). Overall, Harmonic language learners showed a significant preference for harmonic words ($\beta = 1.23$, $SE = 0.23$, $z = 5.39$, $p < 0.001$), whereas Disharmonic language learners did not ($\beta = 0.001$, $SE = 0.21$, $z = 0.005$, $p < 1.00$). Interestingly, Semiharmonic learners' overall numerical preference for harmonic stems was not significantly different from chance ($\beta = 0.41$, $SE = 0.21$, $z = 1.92$, $p = 0.17$). Further, as predicted, Harmonic language learners chose harmonic words significantly more than both Disharmonic learners ($\beta = 1.23$, $SE = 0.26$, $z = 4.80$, $p < 0.001$) and Semiharmonic learners ($\beta = 0.82$, $SE = 0.26$, $z = 3.21$, $p = 0.003$) did. There was no significant difference in the rate of choosing harmonic words between Disharmonic and Semiharmonic learners ($\beta = 0.41$, $SE = 0.24$, $z = 1.68$, $p = 0.17$).

The overall results from the blick test generally confirm that the nature of the phonotactic generalizations learned from the training data differed given the differences in the lexical statistics in the input, the variable that was primarily manipulated. Given this, what kinds of generalizations did participants arrive at in terms of phonological alternations?

WUG TEST: ALTERNATIONS. The rate of choosing correct plurals in all three languages is shown above in Figure 1b. As in the blick test, I was first interested in examining whether the rate of choosing harmonic plurals was proportional to the proportion of harmonic stems in training. The rate of choosing correct plurals was analyzed using a mixed-effects logistic regression model with proportion of harmonic stems in training in each language as a linear independent factor. The model also contained by-subject and by-item random intercepts. This was the maximal model to converge. Participants' performance in the wug test mirrored their performance in the blick test, with the rate of choosing harmonic plurals increasing significantly as a function of the proportion of harmonic stems in the training language ($\beta = 0.022$, $SE = 0.008$, $z = 2.82$, $p = 0.005$). Thus, as in the blick test, the rate of endorsing correct (harmonic) plurals increased in line with the proportion of harmonic stems in training.

To directly compare performance in each language, the rate of choosing correct responses was analyzed using a mixed-effects logistic regression with Language (Harmonic, Disharmonic, and Semiharmonic) as a categorical factor, with random intercepts by subject and item; this was the maximal model to converge. Post-hoc tests were conducted as above. Harmonic learners showed significantly above-chance rates of choosing the correct plural ($\beta = 1.42$, $SE = 0.30$, $z = 4.84$, $p < 0.001$), indicating successful learning of the alternation, whereas the accuracy of Disharmonic ($\beta = 0.30$, $SE = 0.27$, $z = 1.14$, $p = 0.26$) and Semiharmonic learners ($\beta = 0.52$, $SE = 0.27$, $z = 1.95$, $p = 0.15$) was not significantly different from chance. Pairwise comparisons revealed that Harmonic learners learned the alternation significantly better than Disharmonic language learners did (β = 1.12, *SE* = 0.39, $z = 2.86$, $p = 0.01$). The accuracy of Semiharmonic language learners was significantly lower than that of Harmonic language learners (β = 0.90, *SE* = 0.39, $z = 2.30$, $p = 0.04$), and at the same time, not significantly different from that of Disharmonic language learners (β = 0.22, *SE* = 0.37, $z = 0.59$, $p = 0.56$). Thus, Harmonic learners learned the alternation, whereas those in the other two groups did not.

2.4. Correlation between phonotactics and alternations. As seen in the previous sections, the overall performance of participants in the wug test mirrored performance on the blick test. To further investigate the relationship between phonotactic and alternation learning, I examined the correlation between individual learners' performance on the blick test and their performance on the wug test across all three languages. Figure 2 shows each learner's rate of choosing the correct plural in the wug test (strength of alternation learning on the *y*-axis) as a function of their rate of endorsing harmonic stems over disharmonic ones in the blick test (phonotactic learning on the *x*-axis), collapsed across all three language groups. There was a significant positive correlation between the rate of choosing harmonic words in the blick test and the rate of choosing correct harmonic plurals ($R^2 = 0.32$, $r(43) = 0.56$, $p < 0.001$), suggesting that at the level of the individual participant, alternation learning was correlated with phonotactic learning.

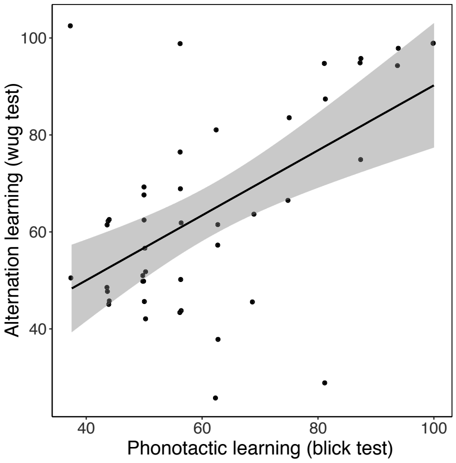


Figure 2. Experiment 1: Correlation between performance in the blick and in the wug tests. The solid black line is the line of best fit, and gray shading indicates 95% confidence intervals.

2.5. Discussion. The results of experiment 1 show that alternations are more difficult to learn when there is a mismatch between stem phonotactic generalizations and the dynamic generalization about alternations. Recall that, across all three languages, the phonological conditioning for the harmony alternation (or allomorph selection) across the morpheme boundary was exactly the same (i.e. the cooccurrence of each allomorph and the harmonizing vowel was exceptionless). In fact, participants in the Disharmonic and Semiharmonic language groups failed to learn it, despite the exceptionless evidence for the alternation in the learning data. Given that the main difference across the language groups was in terms of the proportion of harmonic stems in training, it seems that the alternation learning task is made more difficult if stem phonotactics do not support the dynamic generalization about alternations. More generally, on an individual level, the accuracy of alternation learning correlated with the degree to which each participant inferred a phonotactic constraint about harmonic stems, suggesting further that phonotactic learning aids alternation learning. The results, therefore, provide evidence for a shared mechanism in the learning of phonotactics and alternations.

While there was a significant overall positive linear relation between the proportion of harmonic stems in training and the strength of both phonotactic and alternation learning, there was no significant difference between the Disharmonic and Semiharmonic learners when these groups were directly compared. Further, Semiharmonic learners showed chance-level endorsements of both harmonic stems and correct harmonic plurals. Given that performance by Semiharmonic learners was numerically higher than that of Disharmonic learners, and intermediate between that of Disharmonic and Harmonic learners, it is possible that the study was underpowered with respect to being able to detect a difference between Semiharmonic and Disharmonic learners. I return to this result in the general discussion in §5.3.

To summarize, in experiment 1, learners were poorer at learning alternations when stem phonotactics did not provide support for the alternation. When exposed to a language in which both types of generalizations accorded with each other, participants successfully learned the alternation. Note that Disharmonic learners accurately matched the phonotactic generalization (or lack thereof) in the training data, and failed to learn the alternation. In principle, Disharmonic learners could have instead learned the alternation accurately in the training data and extended that to a preference for harmonic stems over disharmonic ones, going against the static phonotactic information in training. The current results are suggestive of a unidirectional link between phonotactics and alternations.

Experiment 1, however, was not set up to directly examine the directionality of this link since sources of information on both phonotactics and alternations were presented in training. Experiment 2 examines this question more directly. In experiment 2, I examine whether learners are biased to have alternations reflect stem phonotactics without any exposure to the alternation at all. That is, do learners spontaneously expect alternations to reflect stem phonotactics in the absence of any alternation evidence in learning (i.e. do they generalize from static phonotactics to alternations)?

3. EXPERIMENT 2.

It is generally assumed in L1 acquisition that phonotactic learning supports alternation learning due to the fact that morphology is learned later, and morphology is necessary for alternation learning. Experiment 2 was therefore designed to simulate this two-stage process by withholding morphological information in training. Using a poverty-of-stimulus design, experiment 2 examines whether learners spontaneously expect alternations to reflect a learned phonotactic generalization. Participants were trained on the Harmonic and Disharmonic languages used in experiment 1. In experiment 2, however, learners were presented only with singular CVCV stems and were not exposed to plurals in training. Thus, learners had evidence only for a static phonotactic generalization and did not get evidence regarding phonological alternations. If learners spontaneously expect alternations to reflect phonotactic generalizations, then we expect that learners should replicate the performance in the wug test of experiment 1, learning the alternation successfully even without any evidence for this. Such a result would provide strong evidence that phonotactics and alternations are encoded using a single mechanism.

3.1. METHODS.

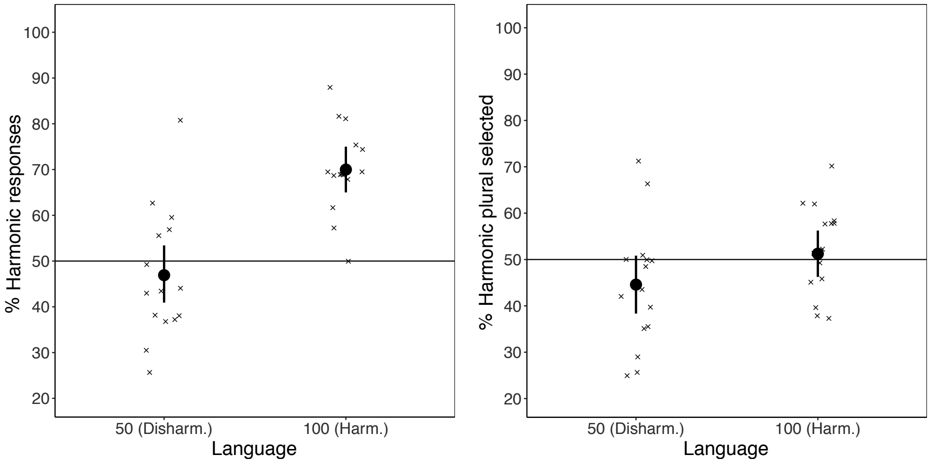
PARTICIPANTS. A total of thirty participants (eight male, twenty-two female; mean age: twenty-one) were recruited from the UCLA Psychology Pool. Participants were randomly put into one of the two artificial language groups (fifteen in each). Six more were tested but were excluded due to having the wrong first language background ($n = 3$), not completing ($n = 2$), or for taking notes in training ($n = 1$).

Stimuli. Given the lack of a difference in learning between the Semiharmonic and Disharmonic languages in experiment 1, in experiment 2 only stimuli from the Harmonic and Disharmonic languages were used.

Procedure. The procedure in experiment 2 was largely the same as that in experiment 1. In training, however, participants were trained only on disyllabic singular stems (with accompanying singular images). Participants were never familiarized on trisyllabic words or plural images. In order to provide the same amount of learning data as in experiment 1, there were six blocks of training instead of the previous three, since initial piloting revealed that phonotactic learning did not occur on just three blocks of training. This was achieved by repeating the three blocks twice, with the order randomized across participants. This ensured that participants were exposed to 192 training trials (as in experiment 1). The two test phases were the same as in experiment 1. As in the wug test in the previous experiment, participants were told that they were going to hear two words for a given image and that they had to pick the word they thought was correct for the language they had just learned. Thus, in the wug test, learners had to generalize a learned phonotactic generalization about disyllabic singular stems to unseen alternations (trisyllabic plurals).

3.2. Results.

Blick test: phonotactic generalizations. The rate of choosing harmonic words in the blick test in experiment 2 (Figure 3a) was analyzed, as in experiment 1, using a mixed-effects logistic regression model. The model contained Language (Harmonic vs. Disharmonic) as a fixed factor, as well as random intercepts by participant and item.



a. Blick test.

b. Wug test.

Figure 3. Experiment 2: Rate of choosing harmonic words in the (a) blick test and (b) wug test. Each black cross represents a single participant, with the large black dot indicating mean rates for each language group with 95% confidence intervals.

Replicating the results of experiment 1, Harmonic language learners chose harmonic words significantly more often than chance ($\beta = 0.91$, $SE = 0.21$, $z = 4.39$, $p < 0.001$) and significantly more often than Disharmonic language learners did ($\beta = 1.05$, *SE* = 0.20, *z* = 5.16, $p < 0.001$). As in both previous experiments, Harmonic language learners inferred a phonotactic preference for harmonic words, whereas Disharmonic language learners did not ($\beta = -0.14$, *SE* = 0.20, $z = -0.72$, $p = 0.47$), following the available evidence in the training data.

Wug test: phonological alternations. The rate of choosing correct plurals in the wug test in experiment 2 (Figure 3b) was analyzed as in experiment 1. A mixed-effects logistic regression with Language (Harmonic vs. Disharmonic) as a fixed factor was fit to participants' responses, with only a by-item random intercept.[5] Unlike in experiment 1, learners' preference for harmonic plurals did not differ significantly from chance (Harmonic: $\beta = 0.05$, *SE* = 0.17, $z = 0.31$, $p = 0.76$; Disharmonic: $\beta = -0.23$, *SE* = 0.17, $z = -1.34$, $p = 0.41$), and there was no significant difference in the rate of choosing correct plurals across the two languages ($\beta = 0.28$, *SE* = 0.19, $z = 1.49$, $p = 0.41$). This indicates that despite inferring a phonotactic generalization that harmonic stems were preferred, Harmonic language learners nevertheless did not spontaneously extend this generalization to a novel morphological domain.

3.3. Discussion.

In experiment 2, Harmonic language learners again succeeded in learning a phonotactic generalization favoring harmonic stems. However, they failed to extend a learned phonotactic generalization to an unseen plural alternation, suggesting that learners are highly conservative in extending phonological generalizations to a novel morphological (or potentially semantic) domain. But it is possible that participants failed to extend the static phonotactic generalization learned in the training phase to novel alternations due to the fact that participants heard only disyllabic stems in training. In the wug test, participants had to generalize to novel trisyllabic forms since all plurals are trisyllabic, as well as to a novel morphological context (i.e. plurals vs. singulars). Thus, their failure to extend the generalization could be due to the novel trisyllabic form of the plurals, which did not appear in training. To investigate this possibility, in experiment 3 I examined whether participants learned the alternation when trained on both disyllabic and trisyllabic stems.

4. Experiment 3: training on trisyllabic stems.

To address the possibility that learners need to have exposure to trisyllabic forms in order to generalize to unseen trisyllabic plurals, in experiment 3 half of the disyllabic stems in the training stimuli were modified to be trisyllabic by adding another CV syllable at the end. Thus, learners were exposed to both disyllabic and trisyllabic stems in training and were then asked to extend the generalization to unseen trisyllabic plurals. So, if learners succeed in generalizing from a stem phonotactic pattern to a phonological alternation when exposed to trisyllabic stems in training, it would suggest that learners do expect alternations to reflect phonotactics but require experience with the relevant word shapes (i.e. trisyllabic words). If, however, participants still fail to generalize to plurals, this would suggest that they require explicit evidence for an alternation in order to learn it, even when the alternation conforms to a learned phonotactic constraint.

4.1. Methods.

Participants. Another thirty participants (five male, twenty-four female, one unreported; mean age: twenty-one) were recruited from the UCLA Psychology Pool. Participants were randomly put into one of the two artificial language groups (fifteen in

---

[5] A model with both by-item and by-participant random intercepts resulted in a singular fit error, indicating overfitting.

each). Nine more were tested but were excluded due to having the wrong first language background ($n = 5$) or not completing the experiment ($n = 4$).

STIMULI. In order to create trisyllabic stems, extra CV sequences were generated from the original set of consonants {p, b, t, d, k, g, m, n} and vowels {i, e, u, o}, with each consonant and vowel occurring equally frequently in this position (each consonant occurred twice and each vowel occurred four times), yielding sixteen novel CVs. These were concatenated with half of the stems (sixteen stems out of thirty-two) in the training data used in experiments 1 and 2 to create trisyllabic stems (e.g. old stem [ˈkete] + new CV [be] → new stem [ˈketebe]). Half of this set of stems were disharmonic in the Disharmonic language, but harmonic in the Harmonic language. The other half were harmonic in both languages. In the Disharmonic language, half of the trisyllabic stems contained [+back][+front][+back] vowel sequences, and half of them [+front][+back][+front] vowel sequences. The resulting training set contained half disyllabic and half trisyllabic stems. Only two languages were used for this experiment: Harmonic and Disharmonic. A full set of stimuli items are shown in Tables A4 and A5 in the appendix. The same test stimuli were used as in experiments 1–2, in order to maintain the ability to compare results across experiments. So, learners needed to decide between disyllabic words only in the blick test.

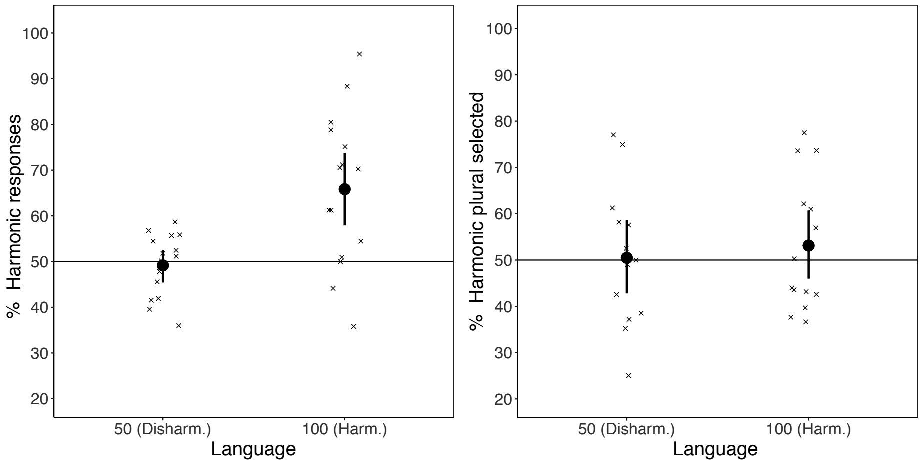
New trisyllabic stems were recorded by the same speaker used for the original stimuli in experiment 1 using PCQuirer (Scicon R&D 2015) at a sampling rate of 22,050 Hz and were rescaled to an average of 70 dB. As in previous experiments, stress was always placed on the initial syllable, voiceless stops were always aspirated, and voiced stops were always voiced throughout the closure.

PROCEDURE. Training in experiment 3 proceeded as in experiment 2, with the sole difference being that there were trisyllabic singular stems in training (e.g. [ˈketebe]). Once training was completed, participants proceeded on to the two test phases, as in experiments 1 and 2.

4.2. RESULTS.

BLICK TEST: PHONOTACTIC GENERALIZATIONS. The rate of choosing harmonic words in the blick test in experiment 3 (Figure 4a) was analyzed using mixed-effects logistic regression with Language (Harmonic vs. Disharmonic) as a fixed factor, along with by-participant and by-item random intercepts. This was the maximal model to converge. Harmonic language learners chose harmonic words significantly above chance ($\beta = 0.68$, $SE = 0.17$, $z = 3.96$, $p < 0.001$), whereas Disharmonic language learners did not show a significant preference ($\beta = -0.03$, $SE = 0.17$, $z = -0.21$, $p = 0.84$). Importantly, Harmonic language learners showed a significantly stronger preference for harmonic words over disharmonic words ($\beta = 0.72$, $SE = 0.19$, $z = 3.70$, $p < 0.001$) compared to Disharmonic language learners. This replicates results of experiments 1–2 that showed different phonotactic learning outcomes between both language groups depending on the presence of disharmonic stems in the lexicon, but with training using trisyllabic as well as disyllabic stems.

WUG TEST: PHONOLOGICAL ALTERNATIONS. Participants' responses (Figure 4b) in the wug test were analyzed, as in previous experiments, using a mixed-effects logistic regression with Language (Harmonic vs. Disharmonic) as a fixed factor, and random intercepts by participant and item (this was the maximal model to converge). Harmonic language learners chose correct (harmonic) plurals at a rate that was not significantly different from chance ($\beta = 0.04$, $SE = 0.19$, $z = 0.19$, $p > 0.50$), as did Disharmonic language



a. Blick test.

b. Wug test.

FIGURE 4. Experiment 3: Rate of choosing harmonic words in the (a) blick test and (b) wug test. Each black cross represents a single participant, with the large black dot indicating mean rates for each language group with 95% confidence intervals.

learners ($\beta = -0.18$, $SE = 0.19$, $z = -0.95$, $p > 0.50$). Importantly, there was no significant difference between the two language groups ($\beta = 0.21$, $SE = 0.26$, $z = 0.82$, $p > 0.50$). Thus, as in experiment 2, participants did not extend the phonotactic generalization about stems, including trisyllabic stems, to novel unseen plurals that involved alternations.

4.3. DISCUSSION. In experiment 3, participants were trained on trisyllabic stems as well as disyllabic stems and could have extended a learned phonotactic generalization about trisyllabic forms to novel plurals that are all trisyllabic. Harmonic language learners, as expected, showed successful learning of phonotactics, at least as indicated by performance on the blick test with disyllabic forms. Yet they failed to extend this generalization to the novel alternation, replicating the behavior with regard to alternations that was seen in experiment 2.

The failure to extend the static phonotactic generalization might be surprising if we consider the fact that learners in Finley and Badecker's (2009) study were able to extend a learned generalization about trisyllabic forms to a novel alternation. The difference, however, between the current experiment and Finley and Badecker's (2009) is that in their experiment, participants were trained explicitly on one harmony alternation (e.g. [bide] ~ [bide-mi], [podu] ~ [podu-mu]) and tested on a different one involving a novel suffix that involved the same abstract generalizations (e.g. [bidi] ~ [bidi-ge] vs. [podo] ~ [podo-go]). That study therefore examined generalization from one alternation to another unseen novel alternation. Here, learners were not trained on any alternations but rather a static phonotactic generalization in singular stems. In the wug test, they then had to extend this generalization to a novel unseen alternation in plurals in a different morphological domain. Thus, this presents a different, and likely more difficult, task from that in Finley & Badecker 2009.

Together, the results of experiments 2 and 3 suggest that learners are conservative in positing alternations when there is no direct evidence for them in the input. They do not extend a learned phonotactic generalization to a novel morphological domain, or novel semantic context, possibly reflecting an anti-alternation bias in early morphophonological learning. An examination of individual learner behavior in experiments 2 and 3 is partially consistent with this possibility: some learners do indeed show a strong preference for one of the two allomorphs, but others do not seem to show a preference at all (see Figure 5 as an example of the distribution of suffix preferences for the Harmonic language in experiment 3; see the supplementary materials for the full data).

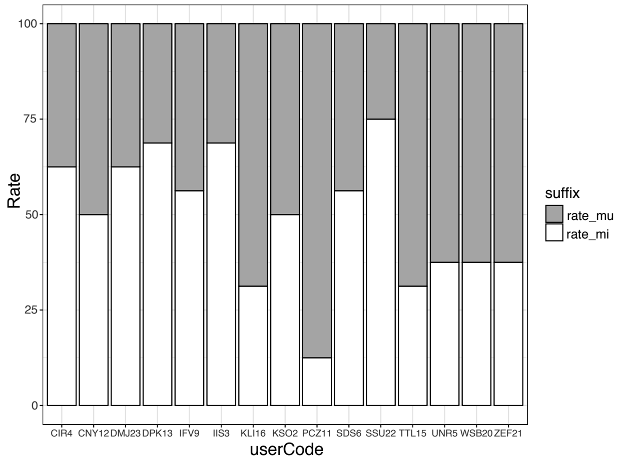


FIGURE 5. Rate of suffix allomorph choice of Harmonic language learners in experiment 3.

5. General discussion. Using a series of artificial grammar learning studies, I investigated how static phonotactic generalizations affect learning of dynamic generalizations involving alternations. Experiment 1 examined alternation learning across languages with varying amounts of phonotactic support. Learning of the alternation was most successful in the Harmonic language, where the phonotactics match the alternation. Learners in both the Semiharmonic and Disharmonic languages, however, did not learn the alternation. While Semiharmonic language learners showed a numerical advantage over Disharmonic learners, this difference did not reach significance. Alternation learning, therefore, is impeded when not supported by phonotactics. In experiments 2 and 3, I investigated whether learners generalize a learned phonotactic generalization to a novel unseen alternation, in order to examine whether there is an initial bias to maintain similar generalizations across both domains. Learners failed to extend a learned phonotactic generalization to a novel unseen alternation regardless of whether they were trained on disyllabic stems (experiment 2) or trisyllabic stems (experiment 3). In the next sections, I discuss the implications these results have for a model of phonotactic and alternation learning, and the grammar, as well as for the learnability of derived-environment patterns.

5.1. Phonotactics and alternations in learning. What does this mean for the relationship between phonotactics and alternations in learning? The results of experiment 1 show that phonotactic mismatches impede the learning of an alternation. This is consistent with the notion that phonotactic and alternation learning are learned through a shared mechanism. Across the different language groups, the amount of evidence for alternations at the morpheme boundary was kept consistent and exceptionless. Thus, the failure of Disharmonic and Semiharmonic language learners to successfully learn the alternation was in spite of there being evidence to support this in the training data—

learners in both of these languages underlearned the alternation. Experiment 1 therefore provides experimental evidence in support of the hypothesis that phonotactics and alternations are learned through a shared mechanism, and that phonotactics facilitates learning of alternations (cf. Pater & Tessier 2005).

While phonotactics and alternation learning seem intertwined, learners are nevertheless conservative in extending a learned static phonotactic pattern to a novel form in a different morphological or semantic domain, as evidenced by the lack of generalization in experiments 2 and 3. This behavior is not predicted by a simple learning model in which phonotactic generalizations are just projected onto novel alternations, or by a learning model in which more general structure-insensitive constraints are preferred (e.g. Martin 2011). Either of these would have predicted that learners in the wug pluralization task would have applied their learned phonotactic generalizations to unseen novel plurals and picked the plural option (from the two options given) that conformed to the learned phonotactic generalization.

Instead, learners are conservative in two possible, nonmutually exclusive ways, both of which arise as reasonable responses to the subset problem (Berwick 1985). For one, learners have been shown to be biased toward nonalternation in the absence of evidence for alternations (McCarthy 1998, Benua 2000, Hayes 2004, Coetzee 2009, Tessier 2007, 2012, Do 2013). In experiments 2 and 3, learners were trained only on singular stems, and did not have any evidence for the alternation in training. The first time they encountered plurals was during the final test phase. Their failure to spontaneously posit an alternation, and the fact that at least some participants also showed a preference for one of the plural suffix forms, is consistent with this initial anti-alternation bias.

Learners' conservatism could also stem from another related source. Learners might be conservative in the morphological domains they posit a phonotactic generalization to hold over (Gallagher et al. 2019). In the current study, a conservative learner might have observed that the only forms they heard in experiments 2 and 3 were singulars and constructed phonotactic generalizations relative to the domain of singulars. In effect, learners might have posited a sublexicon (e.g. Allen & Becker 2015, Becker & Gouskova 2016) or cophonology (e.g. Inkelas et al. 1997, Inkelas & Zoll 2007) of just singular stems (as cued by singular images) and learned a phonotactic constraint that holds of just singular stems. When faced with novel plurals involving suffixation, they fail to generalize spontaneously without further evidence. This is in a similar vein to what Hayes (2004) describes as 'favor specificity'—here the bias to posit the morpheme-specific domain to the phonotactic generalization (i.e. stems) can be seen as an example of this.

For the Harmonic language learners in experiments 2 and 3, assuming nonalternation and the most restricted domain for a particular generalization results in the initial learning of the most restrictive grammar that is consistent with the learning data (Berwick 1985)—that is, harmony, but only in singular stems. At the start of the pluralization task, learners would have noticed that the pattern involves a different morphological context (i.e. plural). This is consistent with Gallagher et al.'s (2019) two-stage learning model in which phonotactic learning is revisited once morphological structure is provided and words can be further segmented into constituent morphemes. Thus, it might have been that learners were at the start of this second morphologically sensitive learning phase in the experiments.

The prediction then is that if learners were trained explicitly on the alternation after a round of pure phonotactic learning, Harmonic learners would learn the alternation pattern rather easily and quickly, compared to learners of either the Disharmonic or Semiharmonic language. The results of experiments 2 and 3 further raise the question of when, and under what conditions, learners in artificial grammar learning studies, and indeed in L1 acquisition, generalize across morphological domains—for example, do learners generalize a phonological constraint to all relevant suffixes or stem types (e.g. nouns vs. verbs)? Or is it necessary for evidence to be given morpheme by morpheme? I leave it to future work to further examine how exactly this transition between morphologically blind and morphology-sensitive learning takes place.

All in all, a learning model (or a model of the phonological grammar) in which phonotactic knowledge about legal sequences within stems and alternation knowledge are acquired completely separately and independently of each other fails to account for the results of experiment 1. Models in which the grammar that governs phonotactics (or MSCs) and phonological rules are completely independent of each other thus fall short in this regard (cf. Paster 2013, Rasin 2016). This also does not support the claim that these static generalizations are computationally inert (e.g. Hale & Reiss 2008). These models would have predicted successful learning of the alternation in all three languages. Yet it is likely that these mechanisms are not completely isomorphic, as a simple OT model with a single (phonotactic) constraint would suggest, and that learning has to be revised in some way once morphological structure is learned (experiments 2 and 3). This could be done through the introduction of both structure-blind and structure-sensitive markedness constraints (Martin 2011), or it could, in principle, even be accommodated under a dual-component architecture. At minimum, however, there needs to be a link spelled out between the two components that possibly encodes some pressure for alternations to reflect phonotactics (cf. Martin 2011).

Elaboration of this link would benefit from examination of how learning occurs in cases where static phonotactic generalizations do not match alternation patterns (or vice versa). Recent computational work has sought to address how learning in these cases might occur. Gallagher et al. (2019), for example, account for the root-bound laryngeal cooccurrence restrictions in Bolivian Aymara in §1.1 above by allowing phonotactic learning to be sensitive to morphological boundaries. They argue for a two-stage process where phonotactic learning first proceeds at the word level, before being reassessed when morphological boundaries are learned. Under a different approach, Whang and Adriaans (2017) presented a model in which phonotactic constraints are less important in determining alternations (Japanese high vowel deletion between voiceless obstruents) that go against a larger phonotactic preference (a general preference for CV syllable structure). In their model, alternations are primarily a lexical process, with phonotactics playing a more minor role of filtering out final candidates that survive an initial lexical grammar. Future work would seek to further test these models against a wider set of cases.

5.2. Learnability of derived-environment effects. In addition to addressing the broader question about the relationship between phonotactics and alternations in learning, the current study has further implications for the learnability of phonological alternations in so-called ‘derived-environment effects’ (Kiparsky 1993). As discussed in §1.1, DEEs involve an active alternation, by which illicit structures are repaired at the morpheme boundary, despite the fact that these same structures are attested within morphemes. In Korean, for example, /t/ is palatalized before [i] across a morpheme boundary, but [ti] sequences are attested stem-internally. To the best of my knowledge, however, no study has examined the learnability of these patterns.

The Disharmonic language in experiment 1 was modeled after a DEE pattern. Learners of this language failed to learn the phonological alternation with cases of mismatching phonotactics, despite being exposed to explicit evidence of an alternation in the learning data. This suggests that alternations involving DEEs are more difficult to learn compared to a language in which alternations and phonotactics match (the Harmonic language in the current study). This further predicts that such language patterns are, all else being equal, dispreferred. In fact, textbook cases of DEEs in which an alternation is not supported by stem-internal phonotactics, but yet is productive in all phonologically relevant derived contexts, seem to be elusive (Chong 2019). In one well-known example of DEE—Turkish velar deletion (Lewis 1967, Zimmer & Abbott 1978, Sezer 1981, Inkelas & Orgun 1995, Inkelas, Orgun, & Zoll 1997, Inkelas 2000, 2011)—the alternation is highly morphologically conditioned (Sezer 1981, Inkelas 2011), applying productively only with polysyllabic nouns (Zimmer & Abbott 1978), and even here is not a categorical pattern (Becker et al. 2011). A careful inspection of the lexicon shows that there is no phonotactic constraint against intervocalic velars in the lexicon (Chong 2019). In fact, many of these DEE patterns seem to fall into this category (Anttila 2006, Inkelas 2011).

This is in contrast to Korean palatalization (Iverson & Wheeler 1988, Kiparsky 1993, Oh 1995, Cho 2001) discussed above. Chong 2019 showed that despite [ti] and [t^hi] sequences being attested within the lexicon, stems with these sequences are exceedingly rare and a computational learner is able to induce a phonotactic constraint against such sequences. At the same time, the alternation is productive across a suffix boundary and not morphologically restricted (Jun & Lee 2007) in the same way as Turkish velar deletion. Taken together, these cases suggest that alternations in putative DEEs are not a unified phenomenon, and possibly are productively learned (i.e. extended to all phonologically relevant morphophonological contexts) only if they are supported by phonotactics. Taken together, the picture that emerges from these studies and the results of the current study suggest that alternation learning in these DEE patterns is more difficult compared to patterns in which alternations and phonotactics match, providing suggestive evidence that these patterns are dispreferred. This is predicted under a model in which phonotactic learning facilitates alternation learning.

What about the learning of Turkish vowel harmony, the pattern on which the Disharmonic language is based? Recall that this is a DEE pattern, since even though vowels in suffixes harmonize to the (final) vowels in roots, there are nonetheless roots that are disharmonic. Is the vowel harmony alternation supported by root phonotactics? To ascertain this, vowel-vowel cooccurrences in 16,757 roots in the Turkish Electronic Living Lexicon (TELL; Inkelas et al. 2001) were calculated. Table 2 shows the number of cooccurrences between front ([−back]) and back ([+back]) vowels. Observed/expected (O/E) values were calculated for each cell. ‘Observed’ (O) values are the total number of times each VV combination is found in the corpus, while ‘expected’ (E) values are how often each VV combination is expected if each V1 and V2 sequence cooccurred based on chance. Expected values were then calculated by taking the product of the relevant marginal totals (row and column) and dividing it by the grand total (for other examples of the use of this measure, see Frisch & Zawaydeh 2001, Coetzee 2008). O/E values are finally calculated by dividing the observed by the expected value. An O/E value of 1 indicates that a particular sequence occurs at the expected rate of occurrence, a value above 1 indicates overrepresentation of that particular VV, and a value under 1 indicates underrepresentation. We note that Disharmonic sequences (cells that are not shaded) are underrepresented, with O/E values under 1, while harmonic VV sequences are overrepresented in the corpus. The vowel harmony alternation in Turkish is thus supported by a harmonic preference in VV sequences in the lexicon despite there being a sizable number of disharmonic sequences. Consistent with this, van Kampen et al.

(2008) and Hohenberger et al. (2016) showed that Turkish infants in the first year of life show early preferences for harmonic words over disharmonic ones. Furthermore, children as young as 2;0 show successful acquisition of vowel harmony in their productions (Aksu-Koç & Slobin 1985), and Turkish adults show awareness of this restriction (Zimmer 1969).

	V2: [−back]	V2: [+back]
V1: [−back]	5,649 (3,776) O/E = 1.50	2,930 (4,803) O/E = 0.61
V1: [+back]	2,683 (4,556) O/E = 0.59	7,669 (5,796) O/E = 1.32

TABLE 2. Occurrence of VV combinations in Turkish: by V1 type (front [−back] vs. back [+back]) and by V2 type (front [−back] vs. back [+back]). Expected counts are in parentheses. The cells in gray indicate harmonic sequences (i.e. [+back][+back] and [−back][−back]).

More generally, if we consider the wider typology of mismatches in phonotactics and alternations (§1.1), the current study, together with the learning models described in the previous section, predicts an asymmetry in the learnability of phonological patterns in which morpheme-internal phonotactics and alternations mismatch. The laryngeal cooccurrence restrictions in Aymara investigated by Gallagher et al. (2019) represent an example where application of a particular process is blocked by a morphological boundary (see §1.1). As described in the previous section, Gallagher et al.'s (2019) computational learner successfully learns these patterns by revisiting phonotactic learning once morphological structure is learned and also by being conservative in positing the level of generalization (within morphemes). If learning is initially biased against alternations, and there is no evidence for the alternation at all, then this type of pattern seems straightforward to arrive at, even if this might go against a learned phonotactic constraint.

The reverse (i.e. DEEs like the Disharmonic language), however, is predicted to be more difficult. The learner must overcome the initial anti-alternation bias as well as possibly posit a structure-sensitive constraint (more complex constraint; Martin 2011), without phonotactic support. Future work therefore would test this prediction more closely and would also examine how much evidence is needed to be able to learn these kinds of patterns. Examining these in more detail, especially from the learning perspective, will be a fruitful avenue for seeing how phonotactics and alternations, as well as morphology, interact in learning.

5.3. OPEN ISSUES. Before concluding, I discuss two further areas in which the current study offers tentative, but inconclusive, results: (i) the influence of frequency on learning and (ii) the unidirectionality of influence between phonotactics and alternation learning. I briefly discuss each of these in turn.

The results of experiment 1 relate to the broader question of how exactly gradient lexical statistics (and exceptions in the lexicon) impacts simultaneous learning of phonotactics and phonological alternations. This is a subject of ongoing research (e.g. Moore-Cantwell & Pater 2016, Zymet 2018). Given that harmonic sequences represented the majority of vowel sequences in the Semiharmonic language in experiment 1, the fact that participants did not reliably endorse harmonic items over disharmonic items is somewhat surprising. Previous studies, for example, have shown that adult speakers show gradient knowledge of phonotactic patterns consistent with lexical statistics in the input (Frisch & Zawaydeh 2001, Coetzee & Pater 2008). What this suggests is that the relationship between frequency and productivity is likely not linear (Coetzee 2009, Moore-Cantwell & Pater 2016). Future work will examine the impact of frequency on the joint learning of phonotactics and alternations, and how much evidence is needed in order to learn these patterns with exceptions.

This study also sheds some light on the directionality of influence between phonotactics and alternation learning. In our experiment it seems that the nature of phonotactic generalizations influences the ability to learn alternations, providing evidence for the flow of information from phonotactics to alternations (cf. Pater & Tessier 2005, Pizzo 2015). What the results of the experiments suggest is that the relation might be unidirectional, and that alternation knowledge may not affect phonotactic knowledge. While the experiment was not set up to test the influence of alternations on phonotactics (as Pizzo 2015 did using a poverty-of-stimulus design), our results provide some suggestive evidence consistent with this unidirectionality. The learners of the Disharmonic language were exposed to an exceptionless alternation pattern. In principle, they could have matched their learning of both the disharmonic stem phonotactic pattern and the exceptionless alternation pattern. But they failed to learn the alternation pattern. If alternation learning influences phonotactic learning, one might have expected the alternation pattern to boost the preference for harmonic stems. Note additionally that if Disharmonic learners were just paying attention to bigram vowel sequences, because vowel sequences across a morpheme boundary always harmonized, there were actually more harmonic vowel sequences than disharmonic sequences overall even in the Disharmonic language, due to the local harmonic sequences across the morpheme boundary with the suffix in experiment 1. Learners therefore failed to learn the alternation despite the global statistical preponderance of harmonic sequences, and the exceptionless alternation pattern involving harmony. Of course, that phonotactics should affect alternations is intuitive given that phonotactics seems to be acquired before alternations in infancy (Friederici & Wessels 1993, Jusczyk et al. 1994, Saffran & Thiessen 2003, White et al. 2008, White & Sundara 2014) and that this can be done without access to morphology. The reverse relationship with alternation learning affecting phonotactic knowledge seems less motivated (Hayes 2004). Overall then our results provide some tentative support of a unidirectionality of flow from phonotactics to alternation, and I leave this open to future investigation.

5.4. CONCLUSION. All in all, in this article I have provided evidence for the basic claim that phonotactics has an impact on alternation learning. At the same time, I have also shown that learners are conservative in extending static phonotactic generalizations to novel alternations, in line with existing models of phonological learning. Together, our results suggest that both types of phonological knowledge cannot be entirely independent of each other in a model of phonological learning, although the specific details of the mechanism that links them is still an open question. I have further shown that patterns like DEEs, which show a mismatch between phonotactics and alternations, are more difficult to learn, predicting that these patterns should be dispreferred crosslinguistically. While the results of the current study indicate that phonotactics and alternations interact in learning, the exact trajectory of learning across both types of phonological knowledge especially in infancy remains unclear. Given the timeline of phonological development in infancy, with phonotactic knowledge emerging before alternation knowledge, it would be illuminating to examine when different kinds of alternation knowledge emerge. The prediction here is that phonotactically supported alternations should be learned first.

APPENDIX: STIMULI LISTS

#	SINGULAR	PLURAL	#	SINGULAR	PLURAL
1	beme	bememi	17	nedi	nedimi
2	pege	pegemi	18	gibe	gibemi
3	degi	degimi	19	nopu	nopumu
4	tipe	tipemi	20	kugo	kugomu
5	mine	minemi	21	gubu	gubumu
6	kipi	kipimi	22	neke	nekemi
7	dimi	dimimi	23	nibi	nibimi
8	podo	podomu	24	dopo	dopomu
9	dobo	dobomu	25	kete	ketemi
10	tonu	tonumu	26	peki	pekimi
11	muto	mutomu	27	tidi	tidimi
12	buno	bunomu	28	gomo	gomomu
13	gutu	gutumu	29	boku	bokumu
14	budu	budumu	30	pime	pimemi
15	tegi	tegimi	31	muko	mukomu
16	motu	motumu	32	kunu	kunumu

TABLE A1. Experiment 1 training items: Harmonic language. Shaded cells indicate harmonic forms.

#	SINGULAR	PLURAL	#	SINGULAR	PLURAL
1	beme	bememi	17	nedi	nedimi
2	pege	pegemi	18	gibe	gibemi
3	degi	degimi	19	nopu	nopumu
4	tipe	tipemi	20	kugo	kugomu
5	mine	minemi	21	gubu	gubumu
6	kipi	kipimi	22	neke	nekemi
7	dimi	dimimi	23	nibi	nibimi
8	podo	podomu	24	dopo	dopomu
9	dobo	dobomu	25	keto	ketomu
10	tonu	tonumu	26	peku	pekumu
11	muto	mutomu	27	tidu	tidumu
12	buno	bunomu	28	gome	gomemi
13	gutu	gutumu	29	boki	bokimi
14	budu	budumu	30	pume	pumemi
15	tegi	tegimi	31	miko	mikomu
16	motu	motumu	32	kuni	kunimi

TABLE A2. Experiment 1 training items: Semiharmonic language. Shaded cells indicate harmonic forms.

#	SINGULAR	PLURAL	#	SINGULAR	PLURAL
1	beme	bememi	17	nodi	nodimi
2	pege	pegemi	18	gube	gubemi
3	degi	degimi	19	nepu	nepumu
4	tipe	tipemi	20	kigo	kigomu
5	mine	minemi	21	gibu	gibumu
6	kipi	kipimi	22	neko	nekomu
7	dimi	dimimi	23	nubi	nubimi
8	podo	podomu	24	dope	dopemi
9	dobo	dobomu	25	keto	ketomu
10	tonu	tonumu	26	peku	pekumu
11	muto	mutomu	27	tidu	tidumu
12	buno	bunomu	28	gome	gomemi
13	gutu	gutumu	29	boki	bokimi
14	budu	budumu	30	pume	pumemi
15	tegi	tegimi	31	miko	mikomu
16	motu	motumu	32	kuni	kunimi

TABLE A3. Experiment 1 training items: Disharmonic language. Shaded cells indicate harmonic forms.

#	SINGULAR	#	SINGULAR
1	beme	17	ketebe
2	pegebi	18	pekipe
3	degini	19	nedi
4	tipege	20	gibe
5	mine	21	tidigi
6	kipi	22	gomonu
7	dimi	23	bokumo
8	podoku	24	nopu
9	dobo	25	kugo
10	tonuto	26	gubu
11	mutoko	27	nekepi
12	buno	28	pime
13	gutu	29	nibi
14	budutu	30	dopodo
15	tegime	31	muko
16	motu	32	kunudu

Table A4. Experiment 3 training items: Harmonic language. Shaded cells indicate harmonic forms.

#	SINGULAR	#	SINGULAR
1	beme	17	ketobe
2	pegebi	18	pekupe
3	degini	19	nodi
4	tipege	20	gube
5	mine	21	tidugi
6	kipi	22	gomenu
7	dimi	23	bokimo
8	podoku	24	nepu
9	dobo	25	kigo
10	tonuto	26	gibu
11	mutoko	27	nekopi
12	buno	28	pume
13	gutu	29	nubi
14	budutu	30	dopedo
15	tegime	31	miko
16	motu	32	kunidu

Table A5. Experiment 3 training items: Disharmonic language. Shaded cells indicate harmonic forms.

#	HARMONIC	DISHARMONIC
1	deke	doke
2	nepe	nepo
3	pemi	pomi
4	tebi	tebu
5	kipe	kupe
6	gike	giko
7	dini	dinu
8	kibi	kubi
9	mogo	moge
10	gono	geno
11	podu	podi
12	bogu	begu
13	buto	bito
14	numo	nume
15	tudu	tudi
16	mutu	mitu

Table A6. Blick test items.

#	SINGULAR	[-mi]	[-mu]
1	mete	metemi	metemu
2	beke	bekemi	bekemu
3	neki	nekimi	nekimu
4	mipe	mipemi	mipemu
5	giti	gitimi	gitimu
6	pidi	pidimi	pidimu
7	kobo	kobomi	kobomu
8	konu	konumi	konumu
9	domu	domumi	domumu
10	tugo	tugomi	tugomu
11	tubu	tubumi	tubumu
12	gunu	gunumi	gunumu
13	bepi	bepimi	bepimu
14	dime	dimemi	dimemu
15	pugo	pugomi	pugomu
16	nodo	nodomi	nodomu

Table A7. Wug test items. Shaded cells indicate harmonic plural forms.

REFERENCES

Adriaans, Frans, and René Kager. 2010. Adding generalization to statistical learning: The induction of phonotactics from continuous speech. *Journal of Memory and Language* 62.311–31. DOI: 10.1016/j.jml.2009.11.007.

Aksu-Koç, Ayhan, and Dan I. Slobin. 1985. The acquisition of Turkish. *The crosslinguistic study of language acquisition, vol. 1: The data*, ed. by Dan Isaac Slobin, 839–78. Mahwah, NJ: Lawrence Erlbaum.

Albright, Adam, and Bruce Hayes. 2003. Rules vs. analogy in English past tenses: A computational/experimental study. *Cognition* 90.119–61. DOI: 10.1016/S0010-0277(03)00146-X.

Allen, Blake, and Michael Becker. 2015. Learning alternations from surface forms with sublexical phonology. Vancouver: University of British Columbia, and Stony Brook, NY: Stony Brook University, ms. Online: https://ling.auf.net/lingbuzz/002503.

Anderson, Stephen R. 1974. *The organization of phonology*. New York: Academic Press.

Anttila, Arto. 2006. Variation and opacity. *Natural Language and Linguistic Theory* 24.893–944. DOI: 10.1007/s11049-006-0002-6.

Bates, David; Martin Mächler; Ben Bolker; and Steve Walker. 2015. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67.1–48. DOI: 10.18637/jss.v067.i01.

Becker, Michael, and Maria Gouskova. 2016. Source-oriented generalizations as grammar inference in Russian vowel deletion. *Linguistic Inquiry* 47.391–425. DOI: 10.1162/LING_a_00217.

Becker, Michael; Nihan Ketrez; and Andrew Nevins. 2011. The surfeit of the stimulus: Analytic biases filter lexical statistics in Turkish laryngeal alternations. *Language* 87.84–125. DOI: 10.1353/lan.2011.0016.

Becker, Michael, and Jonathan Levine. 2014. Experigen—an online experiment platform. Online: http://becker.phonologist.org/experigen.

Benua, Laura. 2000. *Phonological relations between words*. New York: Garland.

Berko, Jean. 1958. The child's learning of English morphology. *Word* 14.150–77. DOI: 10.1080/00437956.1958.11659661.

Berwick, Robert C. 1985. *The acquisition of syntactic knowledge*. Cambridge, MA: MIT Press.

Breiss, Canaan, and Bruce Hayes. 2020. Phonological markedness effects in sentence formation. *Language* 96.338–70. DOI: 10.1353/lan.2020.0023.

Chambers, Kyle E.; Kristine H. Onishi; and Cynthia Fisher. 2003. Infants learn phonotactic regularities from brief auditory experience. *Cognition* 87.B69–B77. DOI: 10.1016/s0010-0277(02)00233-0.

Cho, Taehong. 2001. Effects of morpheme boundaries on intergestural timing: Evidence from Korean. *Phonetica* 58.129–62. DOI: 10.1159/000056196.

Chomsky, Noam, and Morris Halle. 1968. *The sound pattern of English*. New York: Harper and Row.

Chong, Adam J. 2016. Learning consequences of derived-environment effects. *Proceedings of the Linguistic Society of America* 1. DOI: 10.3765/plsa.v1i0.3709.

Chong, Adam J. 2017. *On the relation between phonotactic learning and alternation learning*. Los Angeles: University of California, Los Angeles dissertation. Online: https://escholarship.org/uc/item/7235q340.

Chong, Adam J. 2019. Exceptionality and derived-environment effects: A comparison of Korean and Turkish. *Phonology* 36.543–72. DOI: 10.1017/S0952675719000289.

Chong, Adam J., and Megha Sundara. 2015. 18-month-olds compensate for a phonological alternation. *Proceedings of the Boston University Conference on Language Development (BUCLD)* 39.113–26.

Clements, G. Nick, and Engin Sezer. 1982. Vowel and consonant disharmony in Turkish. *The structure of phonological representations (Part II)*, ed. by Harry van der Hulst and Norval Smith, 213–55. Dordrecht: Foris.

Coetzee, Andries W. 2008. Phonological variation and lexical frequency. Ann Arbor: University of Michigan, ms. Online: http://roa.rutgers.edu/article/view/982.

Coetzee, Andries W. 2009. Learning lexical indexation. *Phonology* 26.109–45. DOI: 10.1017/S0952675709001730.

Coetzee, Andries W., and Joe Pater. 2008. Weighted constraints and gradient restrictions on place co-occurrence in Muna and Arabic. *Natural Language and Linguistic Theory* 26.289–337. DOI: 10.1007/s11049-008-9039-z.

Cristià, Alejandrina; Jeff Mielke; Robert Daland; and Sharon Peperkamp. 2013. Similarity in the generalization of implicitly learned sound patterns. *Laboratory Phonology* 4.259–85. DOI: 10.1515/lp-2013-0010.

Cristià, Alejandrina, and Amanda Seidl. 2008. Is infants' learning of sound patterns constrained by phonological features? *Language Learning and Development* 4.203–27. DOI: 10.1080/15475440802143109.

Crothers, John, and Masayoshi Shibatani. 1980. Issues in the description of Turkish vowel harmony. *Issues in vowel harmony: Proceedings of the CUNY Linguistics Conference on Vowel Harmony, May 14, 1977*, ed. by Robert M. Vago, 63–88. Amsterdam: John Benjamins.

Do, Youngah. 2013. *Biased learning of phonological alternations*. Cambridge, MA: MIT dissertation. Online: http://hdl.handle.net/1721.1/84416.

Finley, Sara, and William Badecker. 2009. Artificial language learning and feature-based generalization. *Journal of Memory and Language* 61.423–37. DOI: 10.1016/j.jml.2009.05.002.

Finley, Sara, and William Badecker. 2012. Learning biases for vowel height harmony. *Journal of Cognitive Science* 13.287–327. DOI: 10.17791/jcs.2012.13.3.287.

Fountain, Amy V. 1998. *An optimality theoretic account of Navajo prefixal syllables*. Tucson: University of Arizona dissertation. Online: https://repository.arizona.edu/handle/10150/288795.

Friederici, Angela D., and Jeanine M. I. Wessels. 1993. Phonotactic knowledge of word boundaries and its use in infant speech perception. *Perception and Psychophysics* 54.287–95. DOI: 10.3758/BF03205263.

Frisch, Stefan A., and Bushra Adnan Zawaydeh. 2001. The psychological reality of OCP-Place in Arabic. *Language* 77.91–106. Online: https://www.jstor.org/stable/3087029.

Gallagher, Gillian; Maria Gouskova; and Gladys Camacho Rios. 2019. Phonotactic restrictions and morphology in Aymara. *Glossa: A Journal of General Linguistics* 4(1):29. DOI: 10.5334/gjgl.826.

Goldrick, Matthew, and Meredith Larson. 2008. Phonotactic probability influences speech production. *Cognition* 107.1155–64. DOI: 10.1016/j.cognition.2007.11.009.

Gorman, Kyle. 2013. *Generative phonotactics*. Philadelphia: University of Pennsylvania dissertation.

Hale, Mark, and Charles Reiss. 2008. *The phonological enterprise*. Oxford: Oxford University Press.

Hayes, Bruce. 2000. Gradient well-formedness in optimality theory. *Optimality theory: Phonology, syntax, and acquisition*, ed. by Joost Dekkers, Frank van der Leeuw, and Jeroen van de Weijer, 88–120. Oxford: Oxford University Press.

Hayes, Bruce. 2004. Phonological acquisition in optimality theory: The early stages. *Constraints in phonological acquisition*, ed. by René Kager, Joe Pater, and Wim Zonneveld, 158–203. Cambridge: Cambridge University Press. DOI: 10.1017/CBO9780511486418.006.

Hayes, Bruce, and James White. 2013. Phonological naturalness and phonotactic learning. *Linguistic Inquiry* 44.45–75. DOI: 10.1162/LING_a_00119.

Hayes, Bruce, and Colin Wilson. 2008. A maximum entropy model of phonotactics and phonotactic learning. *Linguistic Inquiry* 39.379–440. DOI: 10.1162/ling.2008.39.3.379.

Hayes, Bruce; Kie Zuraw; Peter Siptár; and Zsuzsa Londe. 2009. Natural and unnatural constraints in Hungarian vowel harmony. *Language* 85.822–63. DOI: 10.1353/lan.0.0169.

Hohenberger, Annette; Asli Altan; Utku Kaya; Özgün K. Tuncer; and Enes Avcu. 2016. Sensitivity of Turkish infants to vowel harmony: Preference shift from familiarity to novelty. *The acquisition of Turkish in childhood*, ed. by Belma Haznedar and F. Nihan Ketrez, 29–56. Amsterdam: John Benjamins.

Hothorn, Torsten; Frank Bretz; and Peter Westfall. 2008. Simultaneous inference in general parametric models. *Biometrical Journal* 50.346–63. DOI: 10.1002/bimj.200810425.

Inkelas, Sharon. 2000. Phonotactic blocking through structural immunity. *Lexicon in focus*, ed. by Barbara Stiebels and Dieter Wunderlich, 7–40. Berlin: Akademie.

Inkelas, Sharon. 2011. Another look at velar deletion in Turkish, with special attention to the derived environment condition. *Puzzles of language: Essays in honour of Karl Zimmer*, ed. by Eser Erguvanlı Taylan and Bengisu Rona, 37–53. Wiesbaden: Harrassowitz.

Inkelas, Sharon. 2015. Confidence scales: A new approach to derived environment effects. *Capturing phonological shades within and across languages*, ed. by Yuchau E. Hsiao and Lian-Hee Wee, 45–75. Newcastle upon Tyne: Cambridge Scholars.

Inkelas, Sharon; Aylin Küntay; Ronald Sprouse; and Cemil Orhan Orgun. 2001. Turkish Electronic Living Lexicon (TELL). *Turkic Languages* 4.253–75. Online: http://www.digizeitschriften.de/dms/resolveppn/?PID=PPN666048797_0004%7CLOG_0039.

Inkelas, Sharon, and Cemil Orhan Orgun. 1995. Level ordering and economy in the lexical phonology of Turkish. *Language* 71.763–93. DOI: 10.2307/415744.

Inkelas, Sharon; Cemil Orhan Orgun; and Cheryl Zoll. 1997. The implications of lexical exceptions for the nature of grammar. *Derivations and constraints in phonology*, ed. by Iggy Roca, 393–418. Oxford: Clarendon.

Inkelas, Sharon, and Cheryl Zoll. 2007. Is grammar dependence real? A comparison between cophonological and indexed constraint approaches to morphologically conditioned phonology. *Linguistics* 45.133–71. DOI: 10.1515/LING.2007.004.

Iverson, Gregory K., and David W. Wheeler. 1988. Blocking and the elsewhere condition. *Theoretical morphology: Approaches in modern linguistics*, ed. by Michael Hammond and Michael Noonan, 325–38. San Diego: Academic Press.

Jaeger, T. Florian. 2008. Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language* 59.434–46. DOI: 10.1016/j.jml.2007.11.007.

Jarosz, Gaja. 2006. *Rich lexicons and restrictive grammars—Maximum likelihood learning in optimality theory*. Baltimore: Johns Hopkins University dissertation.

Jarosz, Gaja. 2011. The roles of phonotactics and frequency in the learning of alternations. *Proceedings of the Boston University Conference on Language Development (BUCLD)* 35.321–33.

Jun, Jongho, and Jeehyun Lee. 2007. Multiple stem-final variants in Korean native nouns and loanwords. *Journal of the Linguistic Society of Korea* [*Eoneohag*] 47.159–87.

Jusczyk, Peter W.; Paul A. Luce; and Jan Charles-Luce. 1994. Infants' sensitivity to phonotactic patterns in the native language. *Journal of Memory and Language* 33.630–45. DOI: 10.1006/jmla.1994.1030.

Kapatsinski, Vsevolod. 2010. Velar palatalization in Russian and artificial grammar: Constraints on models of morphophonology. *Laboratory Phonology* 1.361–93. DOI: 10.1515/labphon.2010.019.

Kapatsinski, Vsevolod. 2013. Conspiring to mean: Experimental and computational evidence for a usage-based harmonic approach to morphophonology. *Language* 89.110–48. DOI: 10.1353/lan.2013.0003.

Kapatsinski, Vsevolod. 2017. Learning a subtractive morphological system: Statistics and representations. *Proceedings of the Boston University Conference on Language Development (BUCLD)* 41.357–72.

Kenstowicz, Michael, and Charles Kisseberth. 1977. *Topics in phonological theory*. New York: Academic Press.

Kari, James M. 1976. *Navajo verb prefix phonology*. New York: Garland.

Kiparsky, Paul. 1993. Blocking in nonderived environments. *Phonetics and phonology 4: Studies in lexical phonology*, ed. by Sharon Hargus and Ellen M. Kaisse, 277–313. San Diego: Academic Press.

Koo, Hahn, and Jennifer Cole. 2006. On learnability and naturalness as constraints on phonological grammar. *Proceedings of ISCA Tutorial and Research Workshop on Experimental Linguistics*, 165–68. Online: https://www.isca-speech.org/archive/exling_2006/papers/exl6_165.pdf.

Lewis, Geoffrey. 1967. *Turkish grammar*. Oxford: Oxford University Press.

Linzen, Tal, and Gillian Gallagher. 2017. Rapid generalization in phonotactic learning. *Laboratory Phonology* 8:24. DOI: 10.5334/labphon.44.

MacEachern, Margaret. 1997. *Laryngeal cooccurrence restrictions*. Los Angeles: University of California, Los Angeles dissertation. Online: https://linguistics.ucla.edu/images/stories/maceachern.1997.pdf.

Martin, Andrew. 2011. Grammars leak: Modeling how phonotactic generalizations interact within the grammar. *Language* 87.751–70. DOI: 10.1353/lan.2011.0096 .

Martin, Alexander, and James White. 2021. Vowel harmony and disharmony are not equivalent in learning. *Linguistic Inquiry* 52.227–39. DOI: 10.1162/ling_a_00375.

McCarthy, John J. 1998. Morpheme structure constraints and paradigm occultation. *Chicago Linguistic Society (The panels)* 32(2).123−50.

McDonough, Joyce. 1991. On the representation of consonant harmony in Navajo. *West Coast Conference on Formal Linguistics (WCCFL)* 10.319–35.

McDonough, Joyce. 2003. *The Navajo sound system*. Dordrecht: Kluwer.

Moore-Cantwell, Claire, and Joe Pater. 2016. Gradient exceptionality in maximum entropy grammar with lexically specific constraints. *Catalan Journal of Linguistics* 15.53–66. DOI: 10.5565/rev/catjl.183.

Moreton, Elliott. 1999. Evidence for phonological grammar in speech perception. *Proceedings of the 14th International Congress of Phonetic Sciences (ICPhS)*, San Francisco, 2215–17. Online: https://www.internationalphoneticassociation.org/icphs-proceedings/ICPhS1999/papers/p14_2215.pdf.

Moreton, Elliott. 2008. Analytic bias and phonological typology. *Phonology* 25.83–127. DOI: 10.1017/S0952675708001413.

Oh, Mira. 1995. A prosodic analysis of nonderived-environment blocking. *Journal of East Asian Linguistics* 4.261–79. DOI: 10.1007/BF01440729.

Onishi, Kristine H.; Kyle E. Chambers; and Cynthia Fisher. 2002. Learning phonotactic constraints from brief auditory experience. *Cognition* 83.B13–B23. DOI: 10.1016 S0010-0277(01)00165-2.

Paster, Mary. 2013. Rethinking the 'duplication problem'. *Lingua* 126.78–91. DOI: 10.1016/j.lingua.2012.11.015.

Pater, Joe. 2007. The locus of exceptionality: Morpheme-specific phonology as constraint indexation. *Papers in optimality theory III* (University of Massachusetts occasional papers in linguistics 32), ed. by Leah Bateman, Michael O'Keefe, Ehren Reilly, and Adam Werle, 259–96. Amherst: GLSA.

Pater, Joe, and Anne-Michelle Tessier. 2005. Phonotactics and alternations: Testing the connection with artificial language learning. *Papers in experimental phonetics and phonology* (University of Massachusetts occasional papers in linguistics 31), ed. by Kathryn Flack and Shigeto Kawahara, 1–16. Amherst: GLSA.

Pizzo, Presley. 2015. *Investigating properties of phonotactic knowledge through web-based experimentation*. Amherst: University of Massachusetts Amherst dissertation. Online: https://scholarworks.umass.edu/dissertations_2/502/.

Prince, Alan, and Paul Smolensky. 2004 [1993]. *Optimality theory: Constraint interaction in generative grammar*. Cambridge, MA: Blackwell.

Pycha, Anne; Pawel Nowak; Eurie Shin; and Ryan Shosted. 2003. Phonological rule-learning and its implications for a theory of vowel harmony. *West Coast Conference on Formal Linguistics (WCCFL)* 22.101–14.

R Core Team. 2015. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. Online: http://www.R-project.org/.

Rasin, Ezer. 2016. Morpheme structure constraints and blocking in nonderived environments. Cambridge, MA: MIT, ms. Online: https://en-humanities.tau.ac.il/sites/personal.tau.ac.il/files/media_server/1882/Rasin2016_Morpheme_structure_constraints_and_blocking_in_nonderived_environments.pdf.

Richtsmeier, Peter T. 2011. Word-types, not word-tokens, facilitate extraction of phonotactic sequences by adults. *Laboratory Phonology* 21.157–83. DOI: 10.1515/labphon.2011.005.

Saffran, Jenny R., and Erik D. Thiessen. 2003. Pattern induction by infant language learners. *Developmental Psychology* 39.484–94. DOI: 10.1037/0012-1649.39.3.484.

Sapir, Edward, and Harry Hoijer. 1967. *The phonology and morphology of the Navaho language*. Berkeley: University of California Press.

Scholes, Robert J. 1966. *Phonotactic grammaticality*. The Hague: Mouton.

Scicon R&D. 2015. PCQuirer. [Software] Los Angeles, CA.

Sezer, Engin. 1981. The *k*/Ø alternation in Turkish. *Harvard studies in phonology*, ed. by G. N. Clements, 354–82. Bloomington: IULC.

Shaffer, Juliet P. 1995. Multiple hypothesis testing. *Annual Review of Psychology* 46.561–84. DOI: 10.1146/annurev.ps.46.020195.003021.

Shih, Stephanie S., and Kie Zuraw. 2017. Phonological conditions on variable adjective and noun word order in Tagalog. *Language* 93.e317–e352. DOI: 10.1353/lan.2017.0075.

Skoruppa, Katrin; Nivedita Mani; Kim Plunkett; Dominique Cabrol; and Sharon Peperkamp. 2013. Early word recognition in sentence context: French and English 24-month-olds' sensitivity to sentence-medial mispronunciations and assimilations. *Infancy* 18.1007–29. DOI: 10.1111/infa.12020.

Skoruppa, Katrin, and Sharon Peperkamp. 2011. Adaptation to novel accents: Feature-based learning of context-sensitive phonological regularities. *Cognitive Science* 35.348–66. DOI: 10.1111/j.1551-6709.2010.01152.x.

Sundara, Megha; James White; Yun Jung Kim; and Adam J. Chong. 2021. Stem-similarity modulates infants' acquisition of phonological alternations. *Cognition* 209: 104573. DOI: 10.1016/j.cognition.2020.104573.

Tesar, Bruce, and Alan Prince. 2007. Using phonotactics to learn phonological alternations. *Chicago Linguistic Society (The panels)* 39(2).209–37.

Tessier, Anne-Michelle. 2007. *Biases and stages in phonological acquisition*. Amherst: University of Massachusetts Amherst dissertation.

Tessier, Anne-Michelle. 2012. Testing for OO-Faithfulness in the acquisition of consonant clusters. *Language Acquisition* 192.144–73. DOI: 10.1080/10489223.2012.660552.

van Kampen, Anja; Güliz Parmaksiz; Ruben van de Vijver; and Barbara Höhle. 2008. Metrical and statistical cues for word segmentation: The use of vowel harmony and word stress as a cue to word boundaries by 6- and 9-month-old Turkish learners. *Language acquisition and development: Proceedings of GALA 2007*, ed. by Anna Gavarró and M. João Freitas, 313–24. Newcastle: Cambridge Scholars.

Whang, James, and Frans Adriaans. 2017. Phonotactics and alternations in the acquisition of Japanese high vowel reduction. *Proceedings of the Boston University Conference on Language Development (BUCLD)* 41.730–43.

White, James. 2014. Evidence for a learning bias against saltatory phonological alternations. *Cognition* 130.96–115. DOI: 10.1016/j.cognition.2013.09.008.

White, Katherine S.; Sharon Peperkamp; Cecilia Kirk; and James L. Morgan. 2008. Rapid acquisition of phonological alternations by infants. *Cognition* 107.238–65. DOI: 10.1016/j.cognition.2007.11.012.

White, James, and Megha Sundara. 2014. Biased generalization of newly learned phonological alternations by 12-month-old infants. *Cognition* 133.85–90. DOI: 10.1016/j.cognition.2014.05.020.

Wilson, Colin. 2006. Learning phonology with substantive bias: An experimental and computational study of velar palatalization. *Cognitive Science* 30.945–82. DOI: 10.1207/s15516709cog0000_89.

Wolf, M. 2008. *Optimal interleaving: Serial phonology-morphology interaction in a constraint-based model*. Amherst: University of Massachusetts, Amherst dissertation.

Zamuner, Tania S.; Annemarie Kerkhoff; and Paula Fikkert. 2012. Phonotactics and morphophonology in early child language: Evidence from Dutch. *Applied Psycholinguistics* 33.481–99. DOI: 10.1017/S0142716411000440.

Zimmer, Karl E. 1969. Psychological correlates of some Turkish morpheme structure conditions. *Language* 45.309–21. DOI: 10.2307/411662.

Zimmer, Karl E., and Barbara Abbott. 1978. The *k*/Ø alternation in Turkish: Some experimental evidence for its productivity. *Journal of Psycholinguistic Research* 7.35–46.

Zymet, Jesse. 2018. *Lexical propensities in phonology: Corpus and experimental evidence, grammar, and learning*. Los Angeles: University of California, Los Angeles dissertation.

Department of Linguistics
School of Languages, Linguistics and Film
Queen Mary University of London
Mile End Road
E1 4NS London, UK
[a.chong@qmul.ac.uk]

[Received 19 September 2019;
revision invited 29 November 2019;
revision received 25 August 2020;
accepted pending revisions 3 October 2020;
revision received 3 November 2020;
accepted 3 November 2020]