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Is the learning of artificial phonotactic rules interfered with by the concurrent experience of English?

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Abstract

Adults can rapidly learn new first-order phonotactic constraints like */f/ only occurs at the beginning of syllables*, by producing strings of nonsense syllables such as "hes feng neg kem". The learning is measured by observing their speech errors, e.g., whether /f/'s then always slip to syllable onset position. Context-dependent (second-order) constraints such as */f/ occurs at the beginning of syllables if the vowel is /æ/, but occurs at the end of syllables if the vowel is /ɪ/* can be learned as well, but errors only follow these constraints after a period of sleep. It has been suggested that the knowledge of newly-learned second-order constraints is isolated from English knowledge in a separate "mini-grammar" and that the creation of the mini-grammar requires a period of sleep. The present study investigates the mini-grammar notion in the learning of first-order constraints, which are learned quickly in a single session. We interleaved trials in which participants produced strings of nonsense syllables with trials in which they repeated English sentences. The English sentences and nonsense sequences either showed the same consonant-position constraints or the opposite constraints. Speech error data showed that the English sentences interfered with the learning of the first-order constraints within the nonsense sequences, suggesting that the constraints in the nonsense context were not separated from ordinary English in a mini-grammar. We hypothesize that the formation of mini-grammars may require consolidation and that no mini-grammar is created for first-order constraint learning.

Keywords: Language diversity; speech errors; phonotactics; implicit learning

Introduction

Every language user knows how to produce and understand their native language. What is less appreciated is that this knowledge is diverse and greatly dependent on context, even for those who are nominally monolingual. We speak differently than we write. We speak differently to young children than to adults, to friends as opposed to strangers, and to native speakers as opposed to foreign-language speakers (e.g., Snow, 1972; DePaulo & Coleman, 1986). On the comprehension side, we understand many different regional and foreign accents, especially as we get more experience (e.g., Thompson, 1991; Cristia et al., 2012). It is as if, instead of a single grammar, we have many of them, and we know which to use when.

Nielsen and Wilson (2008) developed a hierarchical Bayesian account of linguistic learning that separates the resulting knowledge into a main grammar containing context-independent features (e.g., "cat" begins with a /k/; the regular past tense is "ed") and several "mini-grammars" each of which describes the exceptional features of particular contexts (e.g., my mother says "hoagie" instead of "sub sandwich" and she pronounces it with a fronted vowel). Navigating this diversity requires both the main grammar and the mini-grammars.

Recently, the mini-grammar notion has been applied to a methodological issue in the cognitive science of language: How should we think about artificial grammar-learning paradigms? In many such studies, competent speakers of, say, English, experience English-like materials in the laboratory that nonetheless follow non-English rules. The goal of these studies is to discover principles of learning by assessing whether and how the novel rules are learned. Warker (2013) proposed that what is learned in these studies is a mini-grammar in the same way that we learn mini-grammars for different situations or accents.

The current study explores the mini-grammar idea in a particular paradigm: phonotactic learning as measured by speech errors. Warker (2013), Gaskell et al. (2014) and Dell, Kelley, Hwang, and Bian (2021) suggested that the creation of mini-grammar in this learning paradigm may require a sleep consolidation period. Specifically, when one encounters a new context, namely, the newly experienced phonotactics, the changes and learning that occur from experiencing this experimental setting happens not in the main grammar, but in the separate mini-grammar. Then after a period of consolidation, this mini-grammar becomes available when speaking in the experimental task. Warker (2013) also found that the experimental learning of the phonotactic rule was retained by subjects when tested a week later, suggesting that this mini-grammar is not only associated with the experimental context but is also resistant to interference from the everyday English experience. The current study tested this claim by examining a kind of phonotactic learning that, by itself, does not require consolidation. If mini-grammars require consolidation, it then follows that this kind of learning would *not* exist within a mini-grammar and hence should be interfered with by experience with English.

Phonotactic rules and speech errors

Every language imposes constraints regarding where phonemes are placed in syllables. These constraints are called phonotactic rules. For example, in English, /h/ can only occur

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at the beginning of a syllable (in onset position), and /ŋ/ (the 'ng' sound) only occurs at the end of a syllable (in coda position), as in "hang". This phonotactic knowledge is acquired from experience from infancy through adulthood, and it systematically influences both language perception and production (Dell et al., 2021). Furthermore, it has been found that speech errors, specifically phonological slips, reveal phonotactic knowledge in that the slips rarely create illegal sequences (e.g., Fromkin, 2013; Stemberger, 1982). For example, while English speakers might erroneously say "hing the hymn" in place of "sing the hymn", they would not slip into saying "ngis the hymn", as this violates the phonotactic rule of English that /ŋ/ can only occur in the coda position.

The fact that slips obey phonotactic rules can be used to study the implicit learning of the rules. Implicit learning arises through the performance of some task (e.g., producing syllables) and results in changes in performance that reflect the rules present in the stimuli. An experimenter can embed a new phonotactic rule in syllables to be spoken, such as */f/ must always be an onset*, and then examine whether slips of /f/ tend to land in onset positions, thus implicitly demonstrating acquisition of the rule.

First-order phonotactic rule learning

In the original study investigating implicit phonotactic learning, Dell, Reed, Adams, and Meyer (2000) explored the learning of new first-order phonotactic rules. In a first-order rule, a consonant is constrained to appear in a specific syllable position, either the onset or coda. Participants recited strings of four consonant-vowel-consonant syllables, like "hes feng neg kem". Each sequence included one instance of /h/, /ŋ/, /f/, /s/, /m/, /n/, /k/, and /g/. The sequence was recited in time to a metronome three times in a row, in order to facilitate the production of speech errors.

The eight consonants in the sequences were subject to three kinds of restrictions: language-restricted, experiment-restricted, and unrestricted. The two language-restricted consonants (/h/ and /ŋ/) were constrained by English phonotactic rules to certain syllable-positions: */h/ must be an onset and /ŋ/ must be a coda*. There were two experiment-restricted consonants that were artificially constrained to certain positions in the experiment. For example: */f/ must be an onset and /s/ must be a coda*. Thus, /f/ and /s/ are, within the experiment, acting like /h/ and /ŋ/ respectively. The remaining four consonants (e.g., /m/, /n/, /k/, /g/) were unrestricted and occurred both as onsets and codas throughout the experiment. The unrestricted consonants served as a control for the tendency of any slipped consonant to maintain its intended position.

The consonant slips that participants produced in the experiment were classified according to whether the slipping consonant moved to the same or a different position in another syllable. For example, if "hes feg" slipped to "fes feg", the slip of the /f/ would count as "position maintaining", but if "hes feg" slipped to "hef feg", the slip of /f/ would not be position maintaining.

Dell et al. (2000) found that the slips of the language-restricted consonants maintained their syllable-positions 100% of the time. This was expected because we know that slips will obey the phonotactic constraints of the language, in this case English. A slip of "fes heng" to "nges heng" doesn't just involve movement of "ng" to a different syllable position; the movement violates English phonotactics as well. Slips of unrestricted consonants maintained their syllable-position 73% of the time. This was also expected because there is a general tendency for consonants to slip to the same syllable position. The key data concerned slips of the experiment-restricted consonants. If the participants implicitly learned the experimental constraints, then slips involving these consonants should follow the experimental rules, just as slips of language-restricted consonants follow English rules.

And that was what was found: Experiment-restricted consonants maintained their syllable-positions in 96% of speech errors, far more often than did the unrestricted consonants (73%). This "excess legality" of the slips of experiment-restricted consonants over the slips of unrestricted consonants (a 23% difference) measured the learning of the new experimental constraints.

Importantly, although the experiment was a 4-day study, this difference emerged on the first day and in fact was as large on Day 1 as it was on subsequent days. Since then, this rapid learning effect has been replicated many times (e.g., Goldrick, 2004; Kittredge & Dell, 2016; Goldrick & Larson, 2008; Taylor & Houghton, 2005; Warker & Dell, 2015).

Second-order phonotactic rule learning

Additionally, recent research using phonological slips to measure implicit learning has studied more complicated phonotactic rules, such as */f/ must be an onset if the syllable's vowel is /æ/ but /f/ must be a coda if the syllable's vowel is /ɪ/*. These are called second-order vowel-contingent rules, as the legal position of the consonant depends on the vowel.

Warker and Dell (2006) found that slips followed second-order vowel contingent rules, but not on the first day of training. Later studies showed that a period of sleep is necessary for the learning to be observed (Gaskell et al., 2014; Warker, 2013). This need for sleep in this paradigm was observed for other kinds of second-order rules such as a rule in which the position of a restricted consonant depends on whether the syllable is stressed or unstressed (Bian & Dell, 2020; see also, Warker & Dell, 2006; Warker, Dell, Whalen, & Gereg, 2008; Anderson & Dell, 2018). Thus, it appears that the learning of the second-order rules, but not the first-order rules, requires a period of consolidation.

Mini-grammars and consolidation

But why is consolidation needed to learn second-order constraints? According to Gaskell et al. (2014) and Warker (2013), because the experimental second-order rule is incompatible with English rules, specialized associations between the new rule and the experimental context must be acquired to separate the incompatible artificial rules from the English rules. They proposed that the representation of the new second-order rule was a kind of mini-grammar and that the creation of this mini-grammar requires consolidation (see also Dell et al., 2021). They conceptualized the mini-grammar as a connectionist network whose connection strengths would represent the new associations between, for example, a restricted consonant (e.g., /f/), a vowel (e.g., /æ/), and a syllable position (e.g., onset). This network is separate from the main grammar, which was also conceived of as a network. The main grammar would represent, for example, that /ŋ/ must be a coda, but it would have no record of the new rule stored in the mini-grammar.

The laboratory learning involving the nonsense syllables would be isolated in the mini-grammar and could be called upon whenever the participants revisited the experimental procedures with these syllables, just as an English speaker who has adapted to a new accent can use that experience in the future. Key evidence for the mini-grammar was provided by Warker (2013) who demonstrated that the knowledge of the new rule was long-lasting and hence insulated from English experience that would unlearn the rule if it were not kept in a separate mini-grammar.

This brings us to the central point of the current experiment. Following Warker (2013), we propose that during an artificial phonotactic learning experiment, speakers create a separate mini-grammar that is the locus of the knowledge of the newly learned constraints. The mini-grammar is isolated from the main English grammar and does not become functional until a sleep period (Gaskell et al., 2014). Studies of second-order phonotactic rule learning support this hypothesis.

Recall, though, that the learning of first order rules occurs without a consolidation period (Dell et al., 2000; see also Taylor & Houghton, 2005). One reason that has been proposed for why second-order rule learning requires a mini-grammar, and thus requires consolidation, is that a new vowel-contingent rule about consonant position conflicts with the way English works, where vowels are not important predictors of whether consonants are onsets or codas (e.g., Kessler & Treiman, 1997; Dell et al., 2021). This conflict between English and the experiment stimulates the formation of the mini-grammar. However, first-order rule learning may not require a mini-grammar because the new rules do not conflict with the way English works, as individual consonants do vary in their tendency to be onsets or codas. Thus learning a new first-order rule involves simply strengthening or weakening existing biases (e.g., increasing or decreasing the existing tendency for /f/ to be an onset). These changes could occur in the main grammar without the need for a mini-grammar to isolate that learning. If there is a necessary link between consolidation and the formation of a separate mini-grammar, it follows that the learning of first-order rules, at least before a sleep period occurs, will not be stored in a separate mini-grammar. This reasoning, in turn, makes a strong prediction: that experience with English sentences during the experiment should interfere with the learning of new first-order experimental rules.

In the current study, as in the previous phonotactic learning studies, participants repeated nonsense syllables following a first-order rule: */f/ must be an onset and /s/ must be a coda* (or the reverse for half of the participants). But alternating with nonsense sequence trials, they were also asked to repeat short English sentences. These sentences contained the experiment-restricted consonants /f/ and /s/. For half of the participants, the sentences reinforced the rule found in the nonsense sequences. For example, if the nonsense syllables followed the /f/-onset and /s/-coda rule, the sentences adhered to the same rule, as in "The **f**ear**f**ul voi**c**e was ra**s**py and grating". Because this sentence has /f/-onsets and /s/-codas, it matches the nonsense rule. For the other half of the participants, the interspersed English sentences *mismatched* the rule exhibited in the nonsense syllables. If the nonsense syllables followed the /f/-onset and /s/-coda rule, the sentences would exhibit the opposite constraint, such as "The tur**f** **s**tack was **s**o**f**t and earthy".

The key data involve the degree to which the slips made when producing the nonsense syllables follow the rule present in those syllables. In the matching condition, when the interspersed English sentences reinforce the rule found in the nonsense sequences, we expect the slips to strongly follow the rule. In the mismatched condition, if the production of the nonsense syllables were insulated from English experience in a mini-grammar, the slips should follow the nonsense syllable rule just as strongly. If, however, as predicted, no mini-grammar is formed because there is no sleep period, the English sentences for participants in the mismatched condition will interfere with the acquisition of the rule and reduce the nonsense slips' adherence to the rule.

Dell et al. (2000) found a strong effect of first-order phonotactic learning in Experiment 1 and 2, each with eight participant, each doing 96 trials. Each experiment recorded, on each day, 9,216 attempts to produce a syllable. We increased the number of participants to 24, each doing 48 nonsense trials. Thus, 13,824 nonsense syllable production attempts were made.

Method

Participants

Twenty-four native English-speaking undergraduates (16 females) from the University of Illinois at Urbana-Champaign participated in exchange for course credit. Nine additional participants were tested but their data were eliminated from the analysis, due either to their failure to keep time with the metronome (n=4) or to technical problems in the online procedure (n=5).

Stimuli

The nonsense sequences were constructed as in Dell et al. (2000). Each sequence had 4 CVC syllables, using the eight consonants /h, ŋ, f, s, k, g, m, n/, with the vowel spelled using the letter "e" and pronounced as /ɛ/. The eight consonants appeared once in each sequence, four as onsets and four as codas. The placement of the consonants in each sequence was randomly determined, except for the language-restricted and experiment-restricted consonants. Thus, the /h/ always appeared as an onset and the /ŋ/ appeared always as a coda, as constrained by English phonotactics. /f/ and /s/ were constrained within the experiment to appear either only as an onset or only as a coda, depending on the assigned condition. Thus, if the experimental rule was that */f/ must be an onset and /s/ must be a coda*, a possible sequence would be "hes feng meg ken".

Each English sentence had four stressed syllables, which were indicated to the participants by capitalization, as in "the FURious WASP FLEW aWAY". Each sentence had two instances of the experiment-constrained consonants /f/ and /s/, with either the /f/'s as onsets and /s/'s as codas (as in the furious wasp example just above), or the reverse.

Procedure

This was a videoconference-facilitated experiment, in which the participants joined the researchers for the appointment via Zoom online. The stimuli were presented to the participants via a Qualtrics link which the participants had access to on their own computer and shared with the researchers via Zoom's screen sharing option.

There were 96 trials for each participant, 48 nonsense-syllable trials and 48 English-sentence trials. Participants were randomly and equally assigned to one of four conditions, which we will call fes-face, fes-safe, sef-face, and sef-safe. These notations stand for the constraints participants received in their nonsense and English trials. For example, 'fes' indicates the constraint */f/ must be an onset and /s/ must be a coda* in the nonsense trials, whereas 'face' indicates the constraint */f/ must be an onset and /s/ must be a coda* in the English trials. In this way, the nonsense and English rules were either matched (for participants in the fes-face and sef-safe conditions) or mismatched (for participants in the fes-safe and sef-face conditions). We predicted learning (of the rule in the nonsense sequences) to be present in the matched condition, given its similarity to many previous first-order learning experiments. In the mismatched condition, we predicted reduced learning of the rule due to interference from the interspersed English trials, if the first-order learning of the nonsense is not isolated in a mini-grammar. Because there is just one experimental session, there is no consolidation period to allow for its formation.

Both the nonsense sequences and the English sentences were visually presented to the participants using Qualtrics. All of the trials were presented in font size of 15px, using the font Helvetica, centered on the screen. For a nonsense trial, participants saw a sequence such as "fes hes neg kem", and recited it following a computer-generated metronome, matching each syllable to a beat. The nonsense sequences were presented entirely in lower case. The metronome was set such that for each sequence, the participants first read it aloud once at a rate of 1.1 beats per second, and then repeated the sequence three times without a pause at a faster rate of 2.53 beats per second. After the recitation, participants advanced to the next trial at their own pace by clicking the 'next' arrow.

In the English trial, participants saw four English sentences, for example:

the FURious WASP FLEW aWAY.

the FURious WASP FLEW aWAY.
aWAY the FURious WASP FLEW.
the FURious WASP FLEW aWAY.

Notice that there are two distinct sentences in the list, involving some rearrangement of the same words, sometimes with function-word differences in order to make the English sentences comprehensible. This made the sentence repetition task more difficult and engaging. Participants recited the sentences, matching each stressed syllable with a metronome beat. The metronome rates were set as in the nonsense trials. The participants first recited the first sentence at the 1.1/sec rate, and then the next three sentences each at the 2.53/sec rate without pause. The nonsense and English trials alternated. Other than that, their order was randomly determined. All trials were digitally recorded on Zoom.

Before the first experimental trial, the participants practiced reciting in time to the metronome. There were three practice trials. The first practice trial asked participants to speak each syllable in time to a metronome, simulating the nonsense sequence trials. In the other two practice trials, participants were asked to speak each stressed syllable in time to a metronome, simulating the English sentence trials. The participants practiced these several times until they had accurately produced the materials in time with the metronome. Throughout the experimental session, the experimenter listened to the participants' production, and for the nonsense sequences, corrected them if their pronunciation of the vowel was incorrect or their recitations were not in time with the metronome. For the English sentences, the experimenter corrected them if they were not in time with the metronome, or if they repeated the same sentence instead of producing the rearranged sentences shown on the screen. If the participants still exhibited difficulty in following the instructions after correction, their data were eliminated.

Results

Nonsense Trial Results

One coder transcribed and coded the full sets of production trials. There were 576 syllables (1152 consonants) in the nonsense trials for each participant (i.e. 48 four-syllable sequences produced 3 times each at the fast metronome rate).A second coder independently transcribed and coded a subset of the produced syllables across participants to establish reliability. The second coder listened to 96 produced syllables (192 consonant targets) from each of four randomly chosen participants and identified what consonant was produced. Thus, a total of 768 consonant productions were labeled by the second coder. The primary coder had labeled 700 of these as correct productions and identified a non-target consonant for the remaining 68. The labels assigned by the second coder differed from those assigned by the primary coder for only 7 consonant productions, which resulted in 99% agreement in the coding.

Errors involving movement of the language-restricted phonemes (/h/ and /ŋ/) showed a syllable-position maintenance of 100% for both the matched and mismatched conditions (*SE* = 0, based on 295 total errors). That is, all /h/'s slipped to onset positions and all /ŋ/'s slipped to coda positions. This is to be expected because not only are these consonants restricted to their positions during the experiment, they are so restricted for all of English.

Errors involving movement of consonants restricted by experiment-wide constraints, that is, /f/ and /s/, were also classified as to whether or not they maintained their syllable positions. Very high levels of syllable-position maintenance of the slips are expected if the experimental rule was learned. The same determination was made for slips of the unrestricted consonants (/k/, /g/, /m/, and /n/). The rate of position maintenance for these slips constituted the baseline which could be compared to that for the restricted-consonant slips. Table 1 gives the total number of slips that maintained and did not maintain syllable positions for slips involving restricted and unrestricted consonants, as a function of whether the English sentences matched or mismatched the rule for the nonsense syllables.

Table 1: Number of Same-Position and Different-Position Errors in Nonsense Trials.

	Restricted		**Unrestricted**	
	Same	**Different**	**Same**	**Different**
Matched	107	0	232	70
Mismatched	115	10	274	76

The data analysis procedures followed the first-order phonotactic learning data analysis in Dell et al. (2000)'s study. We expected the restricted slip syllable-position maintenance proportions for the nonsense syllables in the matched condition to be close to 100% and considerably greater than for the unrestricted slips. The key question was whether this difference was reduced in the mismatched condition. We tested three planned contrasts on the maintenance proportions: between restricted and unrestricted slips in the matched condition, between restricted and unrestricted slips in the mismatched condition, and the interaction contrast between condition and restrictedness. As in previous studies, nonparametric tests were used to evaluate the contrasts.

In the matched condition, the mean syllable-position maintenance percentage for slips of restricted consonants (*M* = 100%, *SE* = 0) was significantly greater than the mean syllable-position maintenance percentage for the slips of unrestricted consonants (*M* = 73.9%, *SE* = 3.85; Wilcoxon *Z* = 55, $p < 0.01$), replicating the results from Dell et al. (2000) Experiment 1. This result was as expected, with the magnitude of the difference between the syllable-position maintenance of restricted and unrestricted consonants (a 26% difference) close to that obtained for other first-order effects (28%; Anderson & Dell, 2018). Notice, as well, that position maintenance for the restricted slips in this condition is exceptionless, just as it is for slips of /h/ and /ŋ/.

In the mismatched condition, the slips of restricted consonants maintained their syllable-position 92.8% of the time (*SE* = 3.30) while slips of unrestricted consonants maintained their syllable-position 80.8% of the times (*SE* = 2.68; Wilcoxon *Z* = 80, $p < .017$). Although the difference in the syllable-position maintenance between restricted and unrestricted consonant slips is reduced for the mismatched condition (a 12% difference), the difference remained significant. See Figure 1 for a summary. These results demonstrate that English speakers learned the experiment-restricted constraint present in their nonsense sequences expressed through their speech errors. But the key question is whether the learning effect was diminished in the mismatched condition.

We found a significant interaction between restrictedness and match vs. mismatch condition using a nonparametric test. A Mann Whitney U test on the difference between restricted and unrestricted syllable-position maintenance percentages (excess legality) in the nonsense trials found a significant reduction in the mismatched condition (*U* = 99, *p* = 0.038). Thus, the mismatching English sentences interfered with the learning in the nonsense syllables.

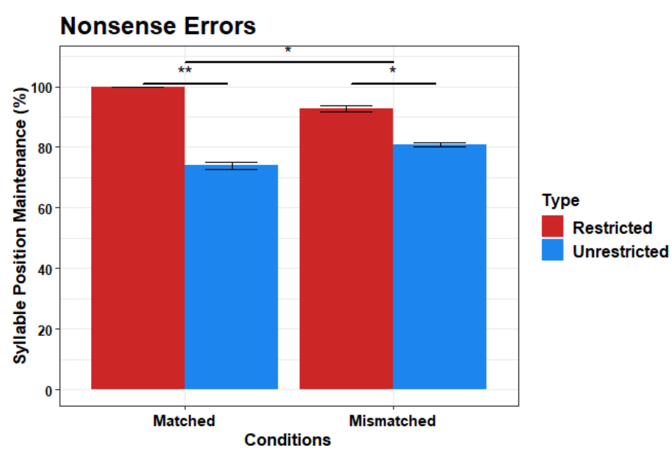

Figure 1: Mean percentage of syllable-position maintenance of consonants and standard error in the nonsense trials for matched and mismatched conditions. The restricted consonants were /f/ and /s/, and the unrestricted consonants were /g, k, m, n/. *Note:* * $p < .05$. ** $p < .01$.

English Trial Results

In the production of the English sentences, we observed many fewer slips overall, as would be expected given that the English materials were much more familiar. This shows that the participants may have treated the English trials as real English sentences that they might encounter in everyday experience, even though the task was unfamiliar to them. We did observe some phonological errors, though, some that involved the restricted consonants /f/ and /s/. While the rate of the restricted consonant errors, that is, slips of /f/ and /s/, in the nonsense trials was 0.1 per each /f/ or /s/ target consonant, the corresponding rate in the English trials was 0.02, five times smaller.[1] The rate was determined by dividing the number of restricted consonant slips by the number of restricted-consonant targets in the stimuli.

In the matched condition, the English restricted consonant slips maintained their syllable position 97.1% of the time. For the mismatched condition, the position maintenance was lower (85.4%), suggesting interference from the nonsense to the English. While it may be tempting to suggest that this difference shows interference from the nonsense to the English, this difference was not significant ($U = 58$, $p = 0.39$), likely because there are many fewer English slips to work with. The direction of the difference is, however, consistent with the conclusion from the nonsense slips—that the English and nonsense trials interfered with each other.

Discussion

The participants learned the first-order phonotactic rule embedded in the nonsense-sequence trials, with the learning revealed in their speech errors involving the restricted consonants. As in previous studies of first-order phonotactic learning, the learning was present in a single experimental session.

The main goal of this experiment, however, was to determine whether the learning was reduced when English sentences were presented in a way that went against the experimentally constrained phonotactic rule in the nonsense strings. Crucially, we found less learning in the mismatched condition, suggesting that the presentation of English sentences had an effect on the learning of the first-order constraints. Thus, the learning of the experiment-imposed constraints in the nonsense syllables seems not to be isolated from the interleaved English experience. We had predicted that this interference would occur based on the idea that the creation of a mini-grammar that isolates the experimental stimuli from English may require a consolidation period (Gaskell et al., 2014). Thus, the present results support this conception of the mini-grammar, at least for these kinds of experiments.

While there was indeed interference, we should ask whether there is nonetheless evidence for some separation between the English and the nonsense in the data. On the surface, the fact that restricted slips showed greater position maintenance than unrestricted slips in the mismatched condition suggests that the English mismatched /f/'s and /s/'s did not completely eliminate sensitivity to the nonsense syllable pattern. However, this result does not unambiguously point to the formation of a mini-grammar protecting the learning in the mismatched condition to some degree. There is a better explanation for the greater maintenance of restricted than unrestricted consonant slips in the mismatch condition. We know that phonotactic learning in this paradigm is highly dependent on error (e.g., Dell et al., 2021; Anderson, Holmes, Dell, & Middleton, 2019). The greater the potential for error during recitation, the greater the learning. Recall that the recitation of the English sentences was much less error-prone than that of the nonsense syllables. Thus the recitation of the English sentences would be much less potent as a learning experience than that of the nonsense sequences. Consequently, even in the mismatched condition, the nonsense pattern remains weakly expressed in the nonsense speech errors.

We have concluded that there is no clear evidence for a mini-grammar representation of the first-order rule during the initial testing session. We should add that, although the mini-grammar is a reasonable account of why learning, specifically second-order learning, persists for up to a week (Warker, 2013), there have been no studies that directly examine interference from concurrent English in these cases. For example, after a sleep period, we predict that both first- and second-order rules would be stored in a mini-grammar and hence would *not* be interfered with by concurrent English. The predicted lack of interference on day 2 for the first-order constraints, in turn, would suggest that the non-conflicting first-order constraints can also create long-lasting learning after consolidation prompted by the distinctive context itself.

As Nielsen and Wilson (2008) pointed out, such isolation is needed to permit language-users to navigate linguistic landscape in which the rules vary across contexts. Specifically, in case of our study, whether the contexts themselves prompt the creation of mini-grammars by virtue of their distinctiveness, or whether a conflict with the larger grammar is required. The results of our current study motivate such tests in pursuit of a greater understanding of the mini-grammar approach to linguistic diversity, and the relationship of artificial language-learning in the lab to learning about that diversity.

In summary, this study is one of the first investigations of the mini-grammar notion as applied to artificial phonotactic learning in the laboratory. The results demonstrated interference between the English and nonsense patterns that occurred during the study. This in turn suggests that, for rapid first-order learning, a strong mini-grammar for the nonsense trials was not created. The results support the claim that the formation of such mini-grammars may require consolidation.

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[1]There were 48 nonsense sequence trials and 48 English sentence trials per participant. Each nonsense sequence had one /f/ target and one /s/ target, and each English sentence had two /f/ and two /s/ targets.

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