Rule Reliability in Natural and Artificial Grammar:
The Case of Velar Palatalization

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Abstract: Russian velar palatalization changes velars into alveopalatals before certain suffixes, including the stem extension –i and the diminutive suffixes –ok and –ek/ik. While velar palatalization always applies before the relevant suffixes in the established lexicon, as depicted by dictionaries, it often fails with nonce loanwords before –i and –ik but not before –ok or –ek. A model of rule induction and weighting (the Rule-based Learner, developed by Albright and Hayes 2003) is trained on the established lexicon of Russian, in which velar palatalization is exceptionless, and tested on new borrowings. Despite the fact that velar palatalization is exceptionless in the training set for every suffix, it is correctly predicted to often fail with novel words before –i and –ik but not before –ek or –ok based on information in the lexicon. This success can be traced to the model’s weighting of competing rules according to their reliability. Reliability-driven competition between rules is shown to predict that a morphophonological rule will fail if the triggering suffix comes to attach to inputs that are not eligible to undergo the rule. This prediction is confirmed in an artificial grammar learning experiment. A method for distinguishing between source- and product-oriented mental grammars is developed and product-oriented generalizations are shown to be unable to account for the data from the examined artificial grammar learning paradigm (Bybee & Newman 1995). The influence of the learning paradigm on the shape of the learned grammar is discussed. Finally, the winning model (the Rule-based Learner) is shown to succeed only if the suffix and the stem shape are chosen simultaneously, as opposed to the suffix being chosen first and then triggering or failing to trigger a stem change and if the choice between competing rules is stochastic.

Introduction

One puzzling phenomenon in language change is the loss of productivity by morphophonemic alternations. Why would an alternation start accumulating exceptions and stop being extended to new words entering the language despite starting out with no exceptions and an abundance of examples supporting it in the lexicon? A particularly interesting historical development happens when an alternation has no exceptions in the lexicon but is not extended fully to new words entering the language. Thus, the alternation loses productivity while not gaining exceptions. In the present paper I will show that a particular alternation, velar palatalization (k→tʃ, g→ʒ), has lost productivity before some Russian suffixes but not others. Velar palatalization has no exceptions in the Russian lexicon, as depicted by dictionaries, before the verbal stem extension –i and the diminutive suffixes –ok and –ek/ik. However, with recent loanwords found in the discourse of Russian-speaking Internet users, velar palatalization fails about 50% of the time before –i and –ik while remaining fully productive before –ek and –ok. Thus Russian provides an opportunity to examine the factors influencing productivity by examining what makes velar palatalization lose productivity before –i and –ik but not before –ek or –ok.

The Rule-Based Learner (RBL, Albright and Hayes 2003) is a computational model that induces rules from a lexicon and weights them relative to each other. The RBL proposes that the productivity of a linguistic rule is determined by its estimated reliability relative to other rules that can apply to the same

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2 Later stages of productivity loss have been documented in wug tests by Zimmer (1969) and Zuraw (2000).
input forms. For instance, suppose we have a language where the velar consonant [k] at the end of a singular stem changes into the alveopalatal [tʃ] when followed by a plural suffix [i]. This singular-plural mapping can be stated as the rule k#→tʃi#. The reliability of a rule is defined by the number of words to which the rule applies divided by the number of words to which it could apply. In the case of k#→tʃi#, this is the number of singular-plural pairs in which a final [k] in the singular corresponds to [tʃ] in the plural divided by the number of singulars that end in [k]. If all singulars that end in [k] correspond to plurals that end in [tʃ], the rule is completely reliable. The more reliable a rule is, the more productive it is expected to be. The present paper is intended to show that reliability-driven competition between rules predicts that a morphophonological rule will lose productivity if the triggering suffix comes to attach mostly to inputs that cannot undergo the rule. This prediction is confirmed both by Russian loanword adaptation data, where –i and –ik are the suffixes that tend not to attach to velar-final inputs whereas –ok and –ek are favored by velar-final inputs, and by data from artificial grammar learning. In both paradigms, the degree of productivity of a palatalizing rule like k#→tʃi is explained by its reliability relative to the more general rule like C#→Ci, which competes with k#→tʃi for velar-final inputs and stipulates that the consonant remains unchanged.

While the RBL is used to model the data in the present paper, it is used only as a representative example of models that embody the hypothesis of statistically resolved competition between source-oriented generalizations. Source-oriented generalizations specify a mapping between a specific category of inputs to a specific category of outputs, e.g., k→tʃi, rather than simply describing what the outputs should be like (Bybee 2001:126-9). This assumption is also made in Analogical Modeling of Language (Skousen 1989), which relies on rule type frequency instead of reliability, and the account of productivity of English velar softening developed in Pierrehumbert (2006). Product-oriented generalizations specify only the shape of the output, e.g., ‘plurals end in /tʃ/’, and are derived via generalization over outputs. A novel product-oriented account that could account for the data is presented in section 3.4. The product-oriented account is argued to require reliability-driven competition between conditional product-oriented generalizations, such as ‘if the plural ends in –i, the preceding consonant must be /tʃ/’, and paradigm uniformity constraints.

Loanword Adaptation in Russian

The pattern in the lexicon

If one looks at a dictionary of modern Russian, velar palatalization appears to involve several exceptionless morphophonological rules, which can be stated simply as “velars become alveopalatals before the derivational suffixes X” where the relevant derivational suffixes either begin with a front vowel or used to begin with a front vowel historically. For the purposes of this article, we will be concentrating on Russian verbs with the highly productive stem extension –i, and the diminutive suffixes for masculine nouns, -ik/ek and -ok, which obligatorily trigger velar palatalization in the lexicon, as depicted by dictionaries (e.g., Levikova, 2003; Sheveleva et al., 1974).

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3 Throughout this paper, by ‘input’ and ‘output’ I mean the input to the rule and the output of the rule, which could both be either underlying or surface forms. A rule here is an input-output mapping, in which both the input and the output are classical categories.

4 While Analogical Modeling of Language is not usually described as rule-based, (supra)context-outcome pairings are input-output mappings in which the input and the output are classical categories.
Example (1) shows that in Russian verbs are derived from consonant-final nouns by adding the stem extension (in this case /i/) followed by verbal inflection (in this case the infinitival marker т). As shown in (1), velars at the ends of noun roots change into alveopalatals when a verb is derived from the root. This does not happen with all stem extensions, as evidenced by the existence of Russian verbs like п'ux+a+t, plak+a+t, and stalk+iva+t, but it always happens with the stem extension -i.

(1)

\[
\begin{align*}
  k & \rightarrow t\text{j}i \\
  klok & \rightarrow klot\text{j}+i+t \\
  durak & \rightarrow durat\text{j}+i+t \\
  polk & \rightarrow polt\text{j}+i+t \\
  jam\text{f}t\text{f}k & \rightarrow jam\text{f}t\text{f}t\text{f}+i+t \\
  g & \rightarrow zi \\
  flag & \rightarrow fla3+i+t \\
  dolg & \rightarrow dol3+i+t \\
  x & \rightarrow f\text{i} \\
  grex & \rightarrow gref\text{i}+i+t
\end{align*}
\]

The mappings between velar consonants and the corresponding alveopalatals are constant across Russian. Thus, if velars change into alveopalatals in some context, /k/ always becomes [t\text{j}], /г/ becomes [z], and /х/ becomes /f/. The Russian phone inventory does not contain [dз]. The phone [i] cannot follow velars or [t\text{j}] while the phone [i] cannot follow [f] or [z]. Whether [i] and [i] are allophones of /i/ and chosen during a separate allophone selection stage or separate stem extensions does not influence the qualitative results presented here. The reported graphs are based on a model that treats the choice between [i] and [i] as happening after the morphophonological competition modeled.

In the Russian lexicon, -а is favored over -i by velar-final roots while -i is favored elsewhere. The distribution in the diminutive system is quite different. Only masculine diminutive suffixes will be considered for the purposes of this paper, because the loaned English nouns end in a consonant, consequently being adopted into the masculine gender. There are three highly productive masculine diminutive suffix morphs, -ик, -ек, and -ок. The morphs -ек and -ик are in complementary distribution in the established lexicon and thus can be considered allomorphs of a single morpheme. The suffixes that trigger palatalization in the lexicon, -ок and -ек, are heavily favored by velar-final nouns, with -ек attaching only to velar-final bases. The suffix -ик, on the other hand, does not attach to velar-final bases, thus one could argue that the Russian lexicon provides no evidence in whether –ик would trigger or fail to trigger velar-palatalization if it were to be attached to a velar-final base, although I will argue that the lexicon does in fact provide the relevant information and Russian speakers use this information in loanword adaptation.5 Examples are shown in (2).

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5 Since -ек and -ик are unstressed, they have the same phonetic realization, the choice between them may be part of orthography. However, the answer to the question of whether the choice is made in orthography or in phonology is not relevant to the modeling of output stem shape as long as the choice of the allomorph follows the decision on whether to change the stem.
(2)

<table>
<thead>
<tr>
<th>Word</th>
<th>Cyrillic</th>
</tr>
</thead>
<tbody>
<tr>
<td>lug</td>
<td>lu'30k</td>
</tr>
<tr>
<td>luk</td>
<td>lu'tfok</td>
</tr>
<tr>
<td>lutf'</td>
<td>'lutfik</td>
</tr>
<tr>
<td>'fartuk</td>
<td>'fartut'fek</td>
</tr>
<tr>
<td>ka'bluk</td>
<td>kablu'tfok</td>
</tr>
<tr>
<td>t'felo'vek</td>
<td>t'felo'vet'fek</td>
</tr>
<tr>
<td>rog</td>
<td>ro'30k</td>
</tr>
<tr>
<td>no3</td>
<td>'no3ik</td>
</tr>
<tr>
<td>j'ag</td>
<td>ja'30k</td>
</tr>
<tr>
<td>t'jas</td>
<td>t'ja'sok</td>
</tr>
<tr>
<td>t'j'as</td>
<td>'tj'asik</td>
</tr>
</tbody>
</table>

**Methods**

**Data collection.** When an English verb is borrowed into Russian, it must be assigned a stem extension. In order to get a sample of such borrowings, I took all verbs found in the British National Corpus retrieved by searching for “*x.[vvi]” in the online interface provided by Mark Davies (http://corpus.byu.edu/bnc/) where ‘x’ is any letter. The resulting verbs were transliterated into Cyrillic.

For each verb, possible Russian infinitival forms were derived. For instance, if the English verb is *lock*, some possible Russian infinitives are /lot'fij/, /lok'itj/, /lok'atj/, /lok'ovatj/ and /lok'irovatj/. Verbs for which an established Russian form already existed (e.g., format > /formatirovatj/) were excluded. Existence was determined by the occurrence in either the Reverse Dictionary of Russian (Sheveleva, 1974), Big Dictionary of Youth Slang (Levikova, 2003), or the present author’s memory. This yielded 472 different verbs. For 56 of them, the final consonant of the English form was a velar, for 99 it was a labial, and for 317 it was a coronal. In the case of the nouns, all possible English monosyllables ending in /k/ or /g/ were created and transliterated into Russian manually. Then possible diminutive forms were created from them and submitted to Google. An additional sample of non-velar-final nouns was then created by matching the distribution of final consonant types in terms of manner and voicing and preceding vowels in the sample of velar-final nouns.

The frequencies of the possible infinitives and nominative diminutives on the web were determined by clicking through the pages of results returned by Google to eliminate identical tokens and to allow Google to ‘eliminate similar pages’, which increases speaker diversity by eliminating results that come from the same server, e.g., different pages from the same bulletin board. In addition, clicking through is necessary when one of the possible forms has a homonym.

Finally, to have a reasonably reliable estimate of the likelihood of failure of velar palatalization before –i for each verb, velar-final verbs and nouns that had 10 or fewer tokens containing the palatalizing suffixes were excluded from the sample. This yielded 36 velar-final verbs and 19 velar-final nouns that could undergo velar palatalization and had a reasonably large number of tokens containing the relevant suffixes.
Modeling

**Introducing the Rule-Based Learner.** The Rule-based Learner (Albright and Hayes 2003) is a computational model of rule induction and weighting. The model starts with a set of morphologically related word pairs as in (3).

(3)

<table>
<thead>
<tr>
<th>mot</th>
<th>motat\textsuperscript{i}</th>
</tr>
</thead>
<tbody>
<tr>
<td>tʃmok</td>
<td>tʃmokat\textsuperscript{i}</td>
</tr>
<tr>
<td>drug</td>
<td>druʒi\textsuperscript{t}</td>
</tr>
<tr>
<td>krug</td>
<td>kruʒi\textsuperscript{t}</td>
</tr>
<tr>
<td>golos</td>
<td>golosovat\textsuperscript{i}</td>
</tr>
</tbody>
</table>

For each word pair, the model creates a word-specific rule as in (4).

(4)

\[
\begin{align*}
[\ ] & \rightarrow a/\text{mot}\_ \\
[\ ] & \rightarrow a/tʃmok\_ \\
g & \rightarrow ʒi/dru\_ \\
g & \rightarrow ʒi/kru\_ \\
[\ ] & \rightarrow ova/_\text{golos}\_
\end{align*}
\]

Then, rules that involve the same change are combined. Contexts in which the same change, e.g., \[\] \rightarrow i, happens are compared by matching segments starting from the location of the change. If segments match, they are retained in the specification of the context for the change and the pair of segments further away from the change is compared. When this comparison process reaches the nearest pair of segments that do not match, the phonological features they share are extracted and retained in the specification of the context. Segments that are further away from the location of the change than the closest pair of non-matching segments are not compared and are replaced by a free variable in the specification of context.

For instance, the rules in (5) are combined into the rule in (6). Since the change involves the end of the stem, comparison starts from the end. The last segments in the context are both /u/, so they are retained and preceding segments are compared. Since the preceding segments are both /r/, they are retained as well and comparison proceeds to the preceding segment. These segments do not match but they are the closest pair of segments to the change that doesn’t match, so the matching features are retained in the rule.

(5)

\[
\begin{align*}
g & \rightarrow ʒi/dru\_ \\
g & \rightarrow ʒi/kru\_
\end{align*}
\]

(6)

\[
\begin{align*}
g & \rightarrow ʒi/[+\text{cons};-\text{cont};-\text{son};-\text{Labial}]\text{ru}\_
\end{align*}
\]

The resulting more general rules are then compared to each other and even more general rules derived if the same change occurs in multiple contexts, eventually resulting in quite general rules, such as \[\] \rightarrow i/C\_. However, all rules are retained in the grammar. Instead of removing non-maximally-general rules from the grammar, the RBL weights each rule by its reliability. Reliability is defined as the number of words to which the rule applies divided by the total number of words to which it could apply. For
instance, the reliability of the rule in (6) is the number of words of the form in (7) that are derived from words with the shape in (8) divided by the total number of words with the shape in (8) in the lexicon.

(7) [+cons;-cont;-son;-Labial]ruʒi
(8) [+cons;-cont;-son;-Labial]rug

A reliable rule is more likely to apply to a novel word than a less reliable rule. For instance, if the rule in (9) is more reliable than the rule in (10), and these are the only rules that can apply to the novel verb /dig/, the verb should be more likely to be borrowed as /diʒi/ than as /diɡa/.

(9) Vg→Vʒi
(10) Vg→Vɡa

The set of rules extracted from the lexicon, i.e., the grammar, is used only on novel words entering the lexicon. Existing morphologically complex words are stored in memory and retrieved from the lexicon as wholes rather than being generated by the rules of the grammar. Storage and retrieval of morphologically complex words is essential for a rule to be able to lose productivity while not gaining exceptions. If existing words were generated by the grammar, they would not continue to obey a rule as the rule loses productivity.

For the purposes of the present paper, this model has four essential features: 1) the model generalizes over input-output mappings, as opposed to just outputs (Bybee 2001:126-129, Pierrhumbert 2006), 2) input-output mappings compete for inputs, 3) the outcome of this competition is driven by reliability, and 4) morphologically complex words are retrieved from the lexicon in production.

Training the model. The model of the stem extension process was presented with the set of stem-verb pairings found in the Reverse Dictionary of Russian (Sheveleva 1974) and/or the Big Dictionary of Youth Slang (Levikova 2003). The Reverse Dictionary contains 125,000 words extracted from the four major dictionaries of Russian that existed in 1965 (Sheveleva et al. 1974: 7). The Slang Dictionary is much smaller, containing 10,000 words. The main results presented below held regardless of whether the Reverse Dictionary, the Slang Dictionary, or both were used. Only the results based on the full training set will be presented. Only stems that occurred independently as separate words were included. No stem extensions were excluded from the training set. Thus, aside from verbs featuring the highly productive –i and –a, verbs having –ova, -irova, -izirova, and –e were also included. The full training set consisted of 2,396 verb-stem pairs, of which 286 stems had final /k/ and 85 had final /ɡ/. There were 22 examples of g→ʒi and 62 examples of k→tʃi. The model of diminutive formation was trained on a set of 1,154 diminutive nouns extracted from the Reverse Dictionary of Russian. All diminutive nouns whose base ends in a consonant were extracted regardless of the diminutive suffix used. The Slang Dictionary contains only a very small number of diminutives and thus was not used.

The learner models competition between input-output mappings. Therefore it is crucial to define what is meant by the input and the output. For the present paper, we are interested in modeling competition between input-output mappings in which some mappings require velar palatalization. The input form for these mappings may or may not have the stem extension already specified. If it does, rules specifying that a velar changes into an alveopalatal compete with rules that retain the consonant in the context of a stem extension that always triggers the change in the lexicon. If not, rules specifying that a
velar changes into an alveopalatal also specify the stem extension. Thus a rule like $k \rightarrow tji$ would compete with $k \rightarrow ka$ as well as $C \rightarrow Ci$.

In addition, the output of the competition can be either a phonetic form, specifying the allophone of /i/ used or a phonemic form, which does not include this specification. Both of these possibilities were examined in modeling but the choice between phonetic and phonemic outputs did not influence the qualitative results. In the case of the diminutive suffixes -ek and –ik, which can be considered allomorphs (or even orthographic variants), it also did not make a difference whether the choice between –ek and –ik followed the stage in which the decision on whether to palatalize the stem was made.

**Testing the model.** The model is presented with the set of English verbs found to be borrowed into Russian in the corpus study. To estimate the probability of a given verb undergoing velar palatalization given that a particular suffix is chosen, we can divide the reliability of the most reliable rule that requires palatalization by the sum of its reliability and the reliability of the rule that does not require palatalization but still attaches the same suffix. For instance, suppose the verb is /dig/ and the model has extracted the rules in (11) with reliability estimates shown in parentheses. The only rules that can apply to /dig/ are (a), (d), (e), (h), (i), and (j). Of these, the only rules that require velar palatalization are rules (h) and (i). Rule (h) is more reliable than rule (i), so it would get to apply. Its reliability is .272. The rule that attaches –i without palatalizing the stem-final /g/ is rule (j). Its reliability is .232. Therefore, the predicted probability that the final consonant of /dig/ will be palatalized, given that –i is selected as the stem extension, is $.272 / (.272 + .232) = 54\%$ (cf. Albright and Hayes, 2003:128).

(11)

<table>
<thead>
<tr>
<th>Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. $[] \rightarrow a/[i;l]g__ (.723)$</td>
</tr>
<tr>
<td>b. $[] \rightarrow a/Cag__ (.718)$</td>
</tr>
<tr>
<td>c. $[] \rightarrow a/[l;r]eg__ (.718)$</td>
</tr>
<tr>
<td>d. $[] \rightarrow a/[i;l;n;r]g__ (.670)$</td>
</tr>
<tr>
<td>e. $[] \rightarrow a/[velar]__ (.641)$</td>
</tr>
<tr>
<td>f. $g \rightarrow 3i/V[^{+back;-high}]__ (.475)$</td>
</tr>
<tr>
<td>g. $g \rightarrow 3i/V[^{+high}]__ (.350)$</td>
</tr>
<tr>
<td>h. $g \rightarrow 3i/V__ (.272)$</td>
</tr>
<tr>
<td>i. $g \rightarrow 3i/[^{+voice}]__ (.195)$</td>
</tr>
<tr>
<td>j. $[] \rightarrow i/C[^{+voiced}]__ (.232)$</td>
</tr>
</tbody>
</table>

**Results**

Figure 1 shows that most velar-final verbs are highly unlikely to take –i while most labial-final and coronal-final verbs are very likely to take –i. Thus, the stem extension that triggers a stem change in the lexicon is disfavored by the stems that can undergo the change.
Since the population distribution is skewed and bimodal, there is no monotonic transformation that will restore normality, which makes standard statistical tests inapplicable, which means that bootstrapping should be done. For this test, I treated the labial-final roots and coronal-final roots as the null population and generated 2,000 samples of 56 verbs from this population, calculating mean rate of taking –i in each sample. The mean rate of taking –i in the sample of velar-final stems (33%) falls very far outside the distribution of 2,000 samples of 56 verbs from the null population, thus $p < .0005 (1/2,000)$. All versions of the model are able to predict that –i is less productive with velar-final stems than with coronal-final and labial-final stems.

Figure 2 shows just the velar-final stems that take –i as the stem extension. These are the only stems that undergo velar palatalization in the data, suggesting that the speakers are using a source-oriented generalization mapping velars onto alveopalatals, rather than a purely product-oriented generalization requiring alveopalatals before –i (Pierrehumbert 2006). A product-oriented generalization specifies only the shape of the output, thus imposing no restrictions on what changes can be done to the input to produce the output (for examples of such product-oriented behavior, see Bybee 2001:126-129).

The white bars show the observed likelihood of failure of velar palatalization before –i in various contexts while the dark bars show probabilities of velar palatalization failure predicted by the model. Figure 2 shows that velar palatalization is more likely to fail with /g/ than with /k/ ($t(26)=4.803, p<.0005$), and when the verb ends in a consonant cluster (left pairs of bars in each box) as opposed to a VC sequence ($t(22)=3.415, p=.003$). There is also a trend for the rule to fail more often after front vowels than after back vowels but it is not statistically significant. In other words, speakers tend to retain the velar if it is /g/ and if it is preceded by a consonant. They tend to replace the velar with an alveopalatal if it is a /k/ preceded by a vowel, especially if the vowel is back.

Despite the fact that the model is trained on a lexicon in which velar palatalization is exceptionless, the model predicts that velar palatalization will not be exceptionless with the borrowed verbs. Mean rate of failure of velar palatalization varies between 43% and 62% depending on parameter settings and approximates the actual mean rate of failure of velar palatalization in the data (56%).
While the mean predicted rate of failure for velar palatalization is similar to the observed rate of failure, the model’s predictions are less variable than the data. In order to make them comparable, failure rates predicted by the model were rescaled to have the same standard deviation as the observed failure rates. The qualitative results shown in Figure 2 hold for all versions of the model that assume that the stem extension and the stem shape are chosen simultaneously. These versions of the model correctly predict that velar palatalization is more likely to fail when the stem ends in a consonant cluster than when it ends in a single consonant, that penultimate front vowels disfavor palatalization compared to back vowels, and that /k/ is more likely to be palatalized than /g/ (however, all versions of the model underestimate the difference between /k/ and /g/). If the stem extension is chosen first with the decision on whether to change the stem consigned to a subsequent decision stage, the predicted rate of failure of velar palatalization is not significantly affected but the effect of penultimate segment identity disappears.

![Figure 2](image-url)

**Figure 2.** Observed (white bars) vs. predicted (grey bars) probabilities of failure of velar palatalization before the stem extension –i depending on segmental content of the stem. (Back and front vowels are not distinguished before [g] because there are relatively few roots ending in [g]).

Observed and predicted rates of failure of velar palatalization in front of diminutive suffixes are shown in Figure 3. As with the stem extensions, velars are the only consonants that change into alveopalatals, suggesting a source-oriented generalization. The rate of failure of velar palatalization is significantly higher before the suffix -ik (mean rate of failure = 40%) than before the suffix -ok (mean rate of failure = 0%), according to the paired-samples Wilcoxon signed ranks test \((Z(16)=3.516, p<.0005)\). Failure of palatalization (which only happens before -ik) is more likely with /g/ (67%) than with /k/ (29%), \(t(15)=2.496, p=.025\). The likelihood of using -ik is lower after /k/ than after /g/ \((t(17)=5.729, p<.0005)\) and is higher after non-velars than after velars \((t(45)=12.461, p<.0005)\). Thus, the

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6 This is why one of the error bars goes negative.

7 This problem is exacerbated when impugnment is used. While versions of the model without impugnment are able to predict that /k/ is more likely to be palatalized than /g/, versions with impugnment incorrectly predict the opposite result except for stems with a penultimate back vowel.
suffixes –i and –ik tend to attach to non-velar-final inputs and often fail to trigger velar palatalization. The suffixes –ek and –ok tend to attach to velar-final inputs and are strong triggers of velar palatalization. Furthermore, in both the domain of verbal stem extensions and nominal diminutives, the productivity of \( k \rightarrow t_f \) is greater than the productivity of \( g \rightarrow z \).

The model successfully learns that –ik is disfavored by velars and that palatalization is likely to fail only if –ik is chosen as the suffix, although the rate of failure of velar palatalization before -ik is overestimated. It predicts that –ek should be more productive with bases ending in /k/ than with bases ending in /g/, a numerical trend in the data. It fails to predict that /k/ is more likely to undergo palatalization and less likely to be followed by –ik than /g/. These predictions are parameter-independent, holding for all versions of the model.

![Figure 3](image.png)

**Figure 3.** Relative likelihoods of various base-diminutive mappings for velar-final and non-velar-final bases of diminutive nouns (likelihoods sum to one across each row of panels) in the data (lines going from upper left to lower right) and in the model (lines going from lower left to upper right). The overlap between observed and predicted probabilities is shown by the intersection of the lines.

**Explaining successes and failures of the model**
In the present study, the RBL is used as only an example of a general class of models that postulate that input-output mappings are involved in a competition that is resolved by the mappings’ relative reliability. Therefore it is important to determine the extent to which the successes and failures of the RBL are due to its reliance on this assumption.

In order to explain why the model performs the way it does let us examine the rules that it abstracts from the lexicon and uses when a velar-final verb is presented. The full list of applicable rules for [g]-final verbs is shown in (11) above. For both [k]-final and [g]-final verbs, there is only one rule that favors adding –i and leaving the final consonant of the stem unchanged. For /g/-final roots, this is the rule C → Ci and for /k/-final roots this is the rule C → Ci. Thus, in order for the more specific rules requiring /k/ to change into /tʃ/ or /g/ to change into /ʒ/ to fail, they must lose to an extremely general rule. For this outcome to be likely, 1) a very general rule must be extracted from the lexicon, 2) it should be quite reliable relative to the less general rules requiring stem changes, and 3) it must compete with those rules.

In the Russian lexicon used to train the model, coronal-final and labial-final stems tend to take –i while velar-final stems tend to take –a. Since most stems in the lexicon end up taking –i, the model extracts a very general rule C → Ci and assigns it a moderate reliability. On the other hand, the fact that velar-final stems favor –a drives down the reliabilities of rules that add other stem extensions to velar-final stems. This includes the rules that add -i and change the root-final consonant. As a result, these rules will sometimes lose the competition for application to the more general rule C → Ci. Thus, the model predicts that velar palatalization will often fail before an affix if and only if the affix is more productive after non-velars than after velars. This holds for the stem extension –i and the diminutive suffix –ik but not for the diminutive suffixes –ek and –ok. Therefore, the model correctly predicts that velar palatalization should fail often before –i and –ik and rarely before –ek and –ok. This prediction follows directly from the hypothesis that input-output mappings compete with the outcome determined by reliability.

The model systematically fails to capture the difference in rate of palatalization between /k/ and /g/, which is observed in both stem extension and diminutive formation. In both cases, the rate of palatalization is underestimated for /k/. Palatalization of /k/ to [tʃ] is much more phonetically natural than palatalization of /g/ to [ʒ]. Bhat (1974:41) notes that velar stops generally become affricates or remain stops as a result of palatalization and if a language palatalizes voiced velars, it also palatalizes voiceless velars but not necessarily vice versa, which suggests that the g→ʒ change is typologically marked. Hock (1991:73-77) proposes that palatalization arises when a fronted velar stop develops a fricative release, suggesting that the velar stop is more similar to an alveo-palatal affricate than to an alveopalatal fricative. In addition, the voiceless velar stop [k] is more acoustically similar to [tʃ] than [g] is to [dʒ] in terms of peak spectral frequency and duration of aperiodic noise, leading listeners to misperceive [ki] as [tʃi] much more often than they misperceive [gi] as [dʒi] (Guion, 1998). Thus, [g] and [ʒ] can be argued to be more perceptually and articulatorily distinct than [k] and [tʃ] and the g→ʒ alternation can be argued to be less phonetically natural than the k→tʃ alternation. Phonetic naturalness has been argued to influence learnability of an input-output mapping when the reliability of the mapping is controlled (Finley and Badecker, to appear; Wilson 2006). The [k]/[g] asymmetry observed in Russian may be another case of this phenomenon. If the palatalization rule for [g] is more difficult to learn than the rule for [k] and the diminutive suffixes –ok and –ek do not permit a velar to precede it without a loss of naturalness, the speaker is driven to choose –ik as the diminutive suffix after [g] more often than after [k], accounting for the relatively high productivity of –ik following [g]. Phonetic naturalness alone cannot account for the data because velar palatalization is much more likely before –ok than before –ik, despite the fact that [o] is a less natural trigger of palatalization than [i].
Another shortcoming of the model is that it overpredicts the rate of velar palatalization before the suffix –ik, especially when –ik attaches to a /k/-final noun. This prediction follows from the fact that –ik never attaches to velar-final inputs in the native lexicon and thus is predicted not to trigger velar palatalization. There are at least two possible explanations for why it should still sometimes trigger velar palatalization. First, the alveopalatal stem-final consonant may be used as a diminutive marker in its own right, especially when the consonant is /t/. This hypothesis is supported by the fact that some labial-final bases take -tjik rather than -ik as the diminutive marker, e.g., sup ‘soup’ → suptjik. Secondly, -ik and –ek are usually phonetically identical due to being unstressed (cf. Shvedova et al., 1980: 27-28). Despite being phonetically identical to -ik, –ek is a much stronger trigger of velar palatalization, thus the two suffixes must constitute different choices in phonology. However, it is possible that some instances of –ik in the (written) data can be cases in which the speaker chose –ek (which triggered velar palatalization) and misspelled it as the more frequent –ik.

**The affix and the stem shape are chosen simultaneously.** Perhaps, the most interesting parameter in the RBL is the sequence of stages assumed in modeling morphophonological processing. Interestingly, the penultimate segment effect on palatalization rate for stem changes is only obtained if a particular assumption is made about the sequence of processing stages, allowing us to distinguish between the two models in (12). Each stage in (12) is modeled by a separate Rule-Based Learner trained on the relevant input-output mappings.

(12)

Two-stage Model:

Stage I:
Choose the suffix based on the borrowed base:
[] → suffix / Base_

Stage II:
Modify the base to fit the suffix:
/Base/ → [Base] /_suffix

One-stage Model:

Stage I:
Choose the suffix based on the borrowed base and modify the base to fit the suffix:
/Base/ → [Base] + suffix

The effects of the penultimate segment shown in Figure 2 (and only those effects) are not predicted if we assume that the stem extension (-i vs. –a) is chosen first, followed by the decision on whether to change the stem (the two-stage model). Let us now examine why this is the case.

In the one-stage model, the palatalizing rules that are applicable to a given stem differ in their reliability, with some rules being more likely to outcompete the general non-palatalizing rule than others. For instance, the stem /overlok/ is likely to undergo velar palatalization because the most reliable palatalizing rule that can apply to it (k→tʃi/l+[cons]+son[o_]) is very reliable (.805) and can easily outcompete the applicable general rule (C→Ci) with its .2 reliability. By contrast, the most reliable palatalizing rule that can apply to the stem /drink/ ([+son]k→[+son]ʃi) has a reliability of only .125, which means that it is likely to lose to the more general rule C→Ci whose reliability is .2, resulting in failure of palatalization.
Suppose instead that the suffix has already been chosen and it is –i. The model now needs to decide whether to palatalize the stem. Interestingly, although the rules changing k→ťʃ and g→ď are exceptionless and thus have a reliability value of 1, they can still sometimes lose to the more general rule “do nothing” because the reliability of “do nothing” is also quite high (86%). This is because most stems in the lexicon take –i and remain the same after the addition of –i.

However, with the stem change choice following affix choice raw reliability predicts no effect of penultimate segment identity. In this model, the reliabilities of all stem-changing rules are at 1, regardless of penultimate segment identity because velar palatalization never fails before –i in the lexicon on which the model is trained. Therefore, the model can capture segmental context effects only if they correspond to differences in rule type frequency (i.e., the number of word pairs supporting the rule), which in this case they do not. Thus, the effect of the penultimate segment is accounted for by the model only if the stem change and the affix are chosen during a single decision stage in which the palatalizing rules compete with rules adding other stem extensions, such as –a (the one-stage model).

Artificial Grammar Learning

Introduction

The data from Russian strongly suggest that the productivity of velar palatalization is connected to whether the palatalizing affix is used mostly with inputs that can undergo velar palatalization or with inputs that cannot. However, the data are correlational in nature, so the direction of causation is uncertain. It is possible that the low productivity of velar palatalization before –iik and –i, whatever its cause, makes speakers of Russian avoid using –i and –iik with velar-final inputs. If changing an input consonant in front of a certain suffix is difficult while keeping the consonant unchanged results in a suboptimal output, the best course of action may be to avoid using the suffix altogether. Furthermore, the dictionary is not a perfect model of the Russian lexicon as it exists in the mind of a Russian speaker. Therefore, the data on whose basis velar palatalization is acquired by the model are different from the data on whose basis velar palatalization is acquired by Russian speakers.

A way to address both of these issues is provided by artificial grammar learning. By training the subjects and the model on the same language featuring velar palatalization, we can maximize the similarities between their relevant learning experiences. Furthermore, by varying the lexical distribution of the palatalizing suffix and keeping all other aspects of the competing rules constant, we can determine whether the distribution of the palatalizing suffix can influence the productivity of palatalization.

Native English speakers were randomly assigned to two groups exposed to two different artificial languages. Both groups were presented with an artificial language featuring two plural suffixes, -a and –i, and an exceptionless rule that palatalized velars before –i, turning /k/ into [ťʃ] and /g/ into [ď]. Since the same input-output mappings are used in languages presented to both groups, phonetic naturalness is controlled. In both languages, velar-final singulars always corresponded to plurals ending in –i or –i. Both subject groups were presented with 30 singular-plural pairs in which the singular ended in a velar. Therefore, the palatalizing rule has the same type (and token) frequency in both languages. The difference between the two languages was that in Language 1 –i was not very productive with non-velar-final singulars, being used in only 25% of the cases with –a being used 75% of the time. In Language 2, the rates were reversed: –a was used 25% of the time with non-velar-final bases while –i was used 75% of the time. In both cases, 40 non-velar-final bases were used. Just like velar-final bases, the non-velar-final

8 For instance, Thomason (1976) proposes that speakers may avoid an affix if it triggers opaque rules.
bases ended in oral stops (/p/, /b/, /t/, and /d/). Non-velar consonants did not change when a suffix was added.

The only rules that are applicable for novel velar-final bases and are extracted by the RBL upon exposure to the two languages are presented in Table 1. As the table shows, the two languages differ only in the reliabilities of the rules that do not require velar palatalization. The rule attaching –i without changing the preceding consonant is much more reliable in Language 2 than in Language 1. Therefore, velar palatalization is predicted to fail before –i in Language 2 more often than in Language 1. Importantly, in both Language 1 and Language 2, the most reliable rules that can apply to a velar-final input are palatalizing. Thus if subjects always used the most reliable applicable rule, there would be no difference between the two languages. Thus, the model predicts a difference between Language 1 and Language 2 only if the choice between rules is probabilistic.

<table>
<thead>
<tr>
<th>Rule</th>
<th>Language 1</th>
<th>Language 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>k→tʃi/V_</td>
<td></td>
<td>0.85</td>
</tr>
<tr>
<td>g→dʒi/V_</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[ ]→i/C_</td>
<td>0.18</td>
<td>0.57</td>
</tr>
<tr>
<td>[ ]→a/C_</td>
<td>0.57</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Table 1. Rules and the corresponding reliability values extracted by the Rule-Based Learner when it is exposed to the same artificial languages presented to human participants.

Methods

The experiment consisted of a training stage and a testing stage. In the training stage, subjects repeated singular-plural pairs presented to them auditorily over headphones. There were 62 word pairs, with each word pair presented twice to each subject during training. The aural presentations of the words were accompanied by visual presentations of the referents on a computer screen. The participants’ productions were used to assess whether the training stimuli were perceived correctly. If a participant made perception errors on more than 5% of singular-plural pairs, s/he was excluded from the experiment (N=2). In the testing stage, subjects were presented with novel singular forms (not presented during training) and asked to orally produce the plural. There were 20 velar-final singulars, and 34 non-velar-final singulars presented during testing. Participants who used –i fewer than 10 times with velar-final singulars (N=4) were excluded from the present analyses. The analyses below are based on thirty participants, half of whom were exposed to each language.

Results and Discussion

First, it is important to note that velars become alveopalatals much more often than other consonants do in both languages (the rate of labials changing into alveopalatals is 0% for both languages; for coronals, it is 2% for Language 1 and 8% for participants exposed to Language 2, a non-significant difference). The difference between rate of coronal palatalization and the rate of velar palatalization is significant for both Language 1 (Wilcoxon signed ranks test, Z(14)=3.05, p<.01) and Language 2 (Z(14)=2.63, p<.01). Thus, there is evidence that subjects really have acquired input-output mappings specifying that velars change into alveopalatals, rather than simply learning that –i should be preceded by an alveopalatal.
The participants were able to discover the distribution of –i and –a in the lexicon. Figure 4 shows that participants exposed to Language 1 used –i after alveolars and labials 30% of the time while participants exposed to Language 2 used –i 67% of the time \((t(28)=4.4, p<.001\). Thus the training was successful in making –i more productive after non-velars in Language 2 than in Language 1. The proportions of –i use by the subjects in the two groups are similar to proportions in the data to which they were exposed: 25% for Language 1 and 75% for Language 2.

![Figure 4](image1.png)

*Figure 4.* Subjects exposed to Language 2 are more likely to use –i to form the plural than subjects exposed to Language 1.

More interestingly, Figure 5 shows that participants exposed to Language 1, the language predicted to favor velar palatalization by virtue of disfavoring the use of –i with non-velar-final singulars, palatalized the velar before -i 67% of the time, while participants exposed to Language 2 palatalized the velar before –i only 38% of the time \((t(28)=2.316, p<.05\). Thus, the predictions of rule reliability are confirmed: even if the rules changing velars into alveopalatals before –i are exceptionless in the language, the more productive –i is with non-velar-final bases, the more likely velar palatalization is to fail.

![Figure 5](image2.png)

*Figure 5.* Subjects exposed to Language 2 are less likely to palatalize the velar before –i than subjects exposed to Language 1.
Like speakers of Russian, subjects exposed to the artificial languages do not simply match the rate of velar palatalization to which they are exposed (100% for all subjects, regardless of whether they were exposed to Language 1 or Language 2). Rather, learners appear to be sensitive to the reliability of the ‘just add –i’ rule relative to the palatalizing rule. Figure 6 shows that there is a strong and significant negative correlation ($r = -.68, p < .001$) between how much a subject uses –i with non-velar-final inputs and how likely s/he is to palatalize a velar before –i.

![Figure 6](image_url)

**Figure 6.** Subjects for whom –i is productive with inputs that cannot undergo velar palatalization are the subjects for whom velar palatalization is unproductive. Curves show the 95% confidence region for the regression line.

Once the correlation between rate of velar palatalization exhibited by a subject and his/her rate of –i use with non-velar-final inputs (Figure 4) is taken into account, the difference between subject groups no longer contributes towards explaining between-subject differences in velar palatalization productivity (according to an ANCOVA with rate of velar palatalization as the independent variable, the rate of –i use with non-velar-final inputs as a covariate, and Language as a fixed factor, rate of –i use is significant, $F(1,27) = 14.23, p < .001$, while Language is not, $F(1,27) = .082, p > .5$). Thus, the difference in productivity of –i with non-velar-final inputs, which is the independent variable predicted to influence productivity of velar palatalization by the RBL, accounts for all differences in productivity of velar palatalization between subjects that can be attributed to the artificial language they are exposed to.

**Source-oriented vs. Product-oriented Generalization**

The present paper has examined the predictions of a rule-based model. We will now examine in more detail whether the same predictions can be derived from a product-oriented and/or constraint-based model. The simplest product-oriented model is one in which the possible generalizations have the form ‘outputs must (not) have X’ (Bybee, 2001). Thus, in the case of our two artificial languages, the relevant palatalizing schemas would have the form ‘plurals end in {t|d3}i (in context X)’. While attractively simple, this account fails to predict a difference between the two artificial languages: since there is the
same number of examples of velar palatalization in both languages, the palatalizing schema has the same type frequency in both languages and is expected to be equally productive.

<table>
<thead>
<tr>
<th></th>
<th>Language 1</th>
<th>Language 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘end in -tʃi/dʒi’</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2.** Palatalizing product-oriented generalizations and the number of plural noun types supporting them in the two languages.

Things get worse if we assume that the learner develops a preference against /ki/, which increases whenever a learner expect to but do not in fact hear it. /Ci/ plurals are more common in Language 2 than in Language 1 while /kV/ plurals don’t occur in either language, thus the learner generalizing over plurals would expect (and fail) to hear /ki/ more often in Language 2 than in Language 1, incorrectly predicting that velar palatalization should be more productive in Language 2 than in Language 1.

<table>
<thead>
<tr>
<th></th>
<th>Language 1</th>
<th>Language 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>*ki/gi</td>
<td>22.5</td>
<td>7.5</td>
</tr>
</tbody>
</table>

**Table 3.** A negative palatalizing product-oriented generalization and the number of times the ungrammatical output is expected but not observed in the two languages.

What seems to be required is a *conditional* product-oriented palatalizing schema of the form ‘if the plural ends in –i, the preceding consonant must be {tʃ; dʒ} (in context X)’. The reliability of this generalization (given as the number of plurals that end in {tʃ; dʒ}i divided by the number of plurals that end in –i) differs between the two languages, since the denominator is much greater in Language 2 than in Language 1, thus palatalization is correctly predicted to fail more often in Language 2 than in Language 1. Equivalently this notion may be formalized as the learner attempting to simultaneously satisfy ‘plurals must end in –{tʃ; dʒ}i’ and ‘plurals must end in –Ci’. The support for the second generalization is greater in Language 2 than in Language 1, thus it will be satisfied more often. The support for the first generalization is the same across the two languages, thus it would be satisfied equally often. Thus the proportion of times a plural ending –i features velar palatalization is expected to be lower in Language 2 than in Language 1.  

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9 A second problem with the product-oriented account is the lack of restrictions on inputs that can give rise to outputs ending in {tʃ; dʒ}i (Pierrehumbert 2006). A possible solution, albeit one relying on generalization over word pairs, is that the palatalizing product-oriented generalization is in competition with some version of paradigm uniformity constraints (see Downing, Hall, and Raffelsiefen, 2005, for possible formalizations), stipulating that the singular and the plural have the same value on the place feature of a stem-final consonant, such as Ident-[velar].
Table 4: A conditional palatalizing product-oriented generalization and the number of times the ungrammatical output is expected but not observed in the two languages.

<table>
<thead>
<tr>
<th></th>
<th>Language 1</th>
<th>Language 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>plurals that end in -tʃi/dʒı</td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>plurals that end in -Ci</td>
<td>38</td>
<td>54</td>
</tr>
<tr>
<td>‘if the plural ends in –ı, the preceding consonant must be {tʃ;дʒ}’</td>
<td>30/38 = .79</td>
<td>30/54 = .56</td>
</tr>
</tbody>
</table>

A crucial difference between the product-oriented accounts and the source-oriented account is the treatment of singular-plural mappings in which the singular ends in {tʃ;дʒ} while the plural ends in {tʃ;дʒ}ı. Under the product-oriented account, these mappings exemplify the palatalizing generalizations ‘plurals must end in −{tʃ;дʒ}ı’ or ‘if the plural ends in –ı, the preceding consonant must be {tʃ;дʒ}’. Thus, their addition to the training set should increase the productivity of velar palatalization. Under the source-oriented account, these singular-plural pairings exemplify the rule ‘just add –ı’, which militates against velar palatalization. Thus, their addition should reduce the productivity of velar palatalization.

A new group of 68 adult native English speakers was presented with one of the four languages in Table 5. Languages I and II are the same languages as the ones presented to the original group of subjects. Languages III and IV differ from Language 1 and Language 2 respectively in having 20 additional singular-plural pairs in which a singular ending in {tʃ;дʒ} corresponded to a plural ending in {tʃ;дʒ}ı.

Table 5. The four languages presented to learners in Experiment II

<table>
<thead>
<tr>
<th></th>
<th>Language 1</th>
<th>Language 2</th>
<th>Language 2I</th>
<th>Language 1V</th>
</tr>
</thead>
<tbody>
<tr>
<td>{k;ɡ} → {tʃ;дʒ}ı</td>
<td></td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>{t;д;p;b} → {t;д;p;b}ı</td>
<td>8</td>
<td>24</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>{t;д;p;b} → {t;д;p;b}а</td>
<td>24</td>
<td>8</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>{tʃ;дʒ} → {tʃ;дʒ}ı</td>
<td>0</td>
<td>20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7 shows that the addition of {tʃ;дʒ} examples reduced the rate of velar palatalization. When the presence of {tʃ;дʒ}→{tʃ;дʒ}ı examples and the probability of attaching –ı to alveolars and labials are entered into an ANCOVA, both are significant (F(1,41) = 23.15, p<.001 for rate of attaching to alveolars and labials; F(1,41) = 6.06, p=.01, for presence of {tʃ;дʒ}→{tʃ;дʒ}ı examples). Thus velar palatalization rate is reduced if –ı often attaches to non-velars, which may be labials and coronals.
This result directly contradicts the hypothesis that the learners are extracting product-oriented generalizations, where the generalization responsible for velar palatalization is ‘plurals must end in {tʃ:dʒ}i’. The examples whose addition reduces the productivity of velar palatalization in the present paradigm exemplify the product-oriented generalization that is supposed to favor velar palatalization. By contrast, the results are expected under the hypothesis that the learners are using source-oriented generalizations. The examples in which an alveopalatal is mapped onto an alveopalatal followed by –i are examples of the rule ‘just add –i’ (C⇒Ci), which disfavors velar palatalization. Thus, at least in the present training paradigm, the generalizations that learners extract from the lexicon are source-oriented.

Conclusion

The hypothesis that rules compete for inputs with the outcome of this competition determined by differences in reliability or type frequency between the competing rules predicts that a morphophonemic rule will lose productivity if the triggering affix comes to be used increasingly with inputs that cannot undergo the rule due to not being in the class of inputs to which the rule can apply. This hypothesis is supported by loanword adaptation data in Russian as well as experimental data from artificial grammar learning.

The present data place three restrictions on the rule-based account. First, the affix and the ‘triggered’ stem change are actually chosen at the same time, rather than the affix being chosen first and then triggering or failing to trigger a stem change. The generality of this finding remains a matter for future research. It is possible that it is a hallmark of phonological processes triggered by specific suffixes or a property of phonological processes occurring in derived environments more generally.
Second, as predicted by Albright & Hayes (2003), the choice between rules must be probabilistic in nature, rather than the subjects always applying the most reliable applicable rule. An important caveat is that the present artificial grammar learning experiments examine generalization in adults. Hudson Kam & Newport (2005) have shown that children exposed to a probabilistic artificial grammar are more prone to regularize the variation, choosing to apply the most productive rule 100% of the time, than adults are. Thus, it would be important to see if the prediction is upheld if the experiment is repeated with children.

Finally, existing morphologically complex words are stored in memory and retrieved for production (cf. Bybee 1985, 2001; Halle 1973; Vennemann 1974), which allows for accurate retrieval of all forms of an existing word accompanied by probabilistic extension of the rules for creating those forms to new words. This feature of natural language is not replicated in the experimental paradigm, where accuracy of plural form production for singulars presented in training is the same as for novel singulars that are first introduced at test. In future work, it is important to modify the experimental paradigm so that learners are asked and enabled to learn individual plural forms.

This modification of the paradigm may make subjects more prone to product-oriented generalization (Bybee, 1985, 2001), which is disconfirmed for the present experimental paradigm but not for the corpus data. In order to determine whether source-oriented generalization in the present artificial grammar learning paradigm is due to characteristics of the training task, future experiments will expose learners with either a singular form or a plural form one at a time, rather than being exposed to singular-plural pairs, and reduce the number of singular-plural pairs to allow for memorization of individual plural forms.

Finally, there is an enormous amount of individual variability in how successful learners are at matching the statistics of the input. This high variability suggests that another fruitful avenue for future research would be correlating the subjects’ generalization behavior in artificial grammar learning with their linguistic experience and success at natural language learning and acquisition. Artificial grammar learning is a precisely controlled experimental paradigm that seems ideally suited for examining the intriguing possibility that poor language learners have different generalization patterns than good language learners.

References


