

# Is Phonotactic Knowledge Grammatical Knowledge?

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## 1. Introduction

Knowledge of phonotactic restrictions refers to one's knowledge of how possible it is for a given sequence of sounds to constitute a word. For example, any native speaker of English is able to distinguish between the acceptability of the forms *bnick* and *blick*; however, the source of this knowledge is far from clear. Some have argued that ratings regarding a string's possibility as a word are related to that string's distance from an actual word or words (Greenberg & Jenkins, 1964), hence invoking access to the lexicon. On this account, a given non-word is compared to existing words in the lexicon, and the acceptability judgment is based on how close to a real word it is, and how many real words it is closely related to with respect to its phonological form (i.e., its phonological neighborhood density). For instance, a non-word like *blick* will have a high rating of acceptability by English speakers, not only by virtue of its similarity to actual words (e.g., it differs in only one phoneme from *black*), but also by the fact that there are many words in its phonological neighborhood, such as *black*, *bliss*, *brick*, etc. Listeners' performances in a variety of tasks, such as lexical decision (Luce & Pisoni, 1998) or phoneme identification (Newman et al., 1996), show that listeners are sensitive to the similarity between a novel form and the lexical items in its phonological neighborhood.

Another view is that the only factor that determines acceptability of a non-word is the grammar. The rendering of a judgment on well-formedness of a non-word relies on well-formedness constraints that are spelled out in the grammar, which means that the grammar is the sole linguistic component engaged in this task. On this view, the lexicon itself plays no role in deeming a form unacceptable, aside from the fact that grammatical constraints are ranked on the basis of words that are learned and stored in the lexicon. There have been attempts to provide a complete generative analysis that accounts for speakers' phonotactic knowledge (e.g., Clements & Keyser, 1983; Hammond, 1999). For example, in the phonological analysis offered by Clements & Keyser (1983), a novel form such as *bnik* is judged as ungrammatical on the basis of a positive syllable structure condition that requires syllable-initial clusters to have the following parameters: [-sonorant][+sonorant, - nasal].

A defect of current grammatical accounts of phonotactics is that they render simple up-or-down decisions concerning well-formedness and cannot account for gradient judgments. But when judgments are elicited in a controlled fashion from speakers, they always emerge as gradient, including all intermediate values. For example, speakers accept novel forms [bɪs] and [glɔrm] as well-formed, as opposed to [rɪtk] which they judge as ill-formed. Nevertheless, they rate [bɪs] higher than [glɔrm]. In addition to the fact that grammatical accounts are unable to capture speakers' gradient judgments, they may not be empirically adequate. For example, Trieman et al. (2000) showed that adults are sensitive to the statistics of the lexicon. They identified VC pairs in English that could be transformed into less frequent pairs by switching the consonant members; that is, their stimuli were high frequency  $V_1C_1 - V_2C_2$  pairs that could be transformed to low frequency  $V_1C_2 - V_2C_1$  pairs (e.g., /ɪm/ and /ab/ transformed to /ɪb/ and /am/). Subjects in their experiment were presented with monosyllabic non-word stimuli that were constructed based on the above-described VC pairs. This allowed Trieman et al. (2000) to control for phoneme frequency, while they tested for subjects' implicit knowledge of rime frequencies. The subjects judged the higher frequency rimes as better than the low frequency rimes. The results of the study, therefore, reveal that native speakers are not sensitive simply to phoneme frequency, but they are sensitive to the frequency of sound sequences in a particular structure (e.g., rimes).

There are additional lines of evidence indicating that perceived well-formedness of non-words is related to the frequency of particular sound sequences in the language. Phonotactic probability has been correlated with performance on a variety of psycholinguistic tasks, such as non-word repetition (Vitevitch et al., 1997; Vitevitch & Luce, 1998), phoneme identification (Pitt & McQueen, 1998), and wordlikeness (Coleman & Pierrehumbert, 1997; Dankovicova et al., 1998).

The main issue here is that the speakers' performances have been repeatedly found to be gradient with respect to processing of novel forms (Ohala & Ohala, 1986; Coleman & Pierrehumbert, 1997; Frisch et al., 2000; Albright & Hayes, 2003; Hay et al., 2004; Hammond, 2004; Vitevitch & Luce, 2005; Albright, 2006). The establishment of formal models that can predict such patterns of gradience remains an unsolved problem for generative phonology. In the experiments that follow, I will be employing, as a "stand-in" for rule based accounts, the model of Coleman and Pierrehumbert (1997), which does have the virtue of using authentic phonological constituents (onset and rimes), and using them to make gradient predictions.

Thus, there are two fundamentally different approaches to modeling phonotactic intuitions, based on analogy with existing forms, and based on the rules or constraints of a grammar. Moreover, the possibility should not be excluded that *both* factors play a role in native speaker judgments. Just this claim has been made by Bailey and Hahn (2001), who offered a sophisticated experimental design intended to tease apart the two effects. Bailey and Hahn compared three measures of phonotactics effects: Bigram, trigram transitional probabilities, and syllable-part probability (with units as onset, nucleus, and coda). In order to measure the effects of lexical neighborhood, they used the Generalized Neighborhood Model (GNM). This model is an adaptation of Nosofsky's Generalized Context Model (1986). The GNM assesses neighbors that are two-phoneme edit distances away. Edit distance is a weighted sum of the substitutions, insertions, and deletions required to transform one word (or non-word) to another word. While edit distance is usually used with equal weights attached to all substitutions, the GNM aims for a more realistic measure that takes into consideration the varying weight depending on the phonological differences that reflect the nature of the substitution. In other words, in the GNM, *duck* is not the same distance from both *tuck* and *suck* because the /d/ and /t/ have fewer phonological differences between them than /d/ and /s/. In addition, a frequency-weighting term is incorporated into the similarity equation that allows for non-monotonic effects. In other words, the effect of frequency is such that the medium-frequency words had the strongest effect.

Bailey and Hahn (2001) found that subjects' ratings reflect effects that are due to phonotactic probability and lexical probability. More importantly, they report that not only are the lexical effects not subsumed by sequence typicality, but that lexical effects have a more important role than phonotactic probability in predicting the well-formedness ratings. These results suggest an interaction of both components of language, lexicon and grammar, in a task that requires rating of the phonological acceptability of novel forms.

The new evidence brought to bear on the debate here concerns a novel effect: the balance between the two mechanisms, lexical analogy and grammatical knowledge, can be changed by altering the experimental procedure. Two experiments are reported in which the crucial difference is whether, or not, real words are included in the stimulus set. The results suggest that the effect of lexical similarity is sensitive to the presence of real words in the stimuli, while the effect of phonotactic probability is not. At the close of the paper I will offer some speculations for why this should be so.

## 2. Experiment 1 – Novel Words

*Participants.* Participants were 24 undergraduates from the University of California, Los Angeles. The students participated in the experiment as part of their Introduction to Linguistics course. All participants were native speakers of American English.

*Stimulus Selection.* The goal of this experiment was to achieve a balanced design in which the stimuli were distinguished based on which mechanism (phonotactic probability and lexical similarity) would render them as acceptable English words. In order to select the appropriate words for the

stimulus set, it was imperative to have a measure to assess the presence of each effect. Measures of grammatical and lexical effects are discussed below.

*Assessing the grammatical mechanism.* As an approximation of a phonological grammar, the probabilistic grammar of Coleman and Pierrehumbert (1997) was used. Coleman & Pierrehumbert (1997) studied phonotactic acceptability and the statistical correlation of acceptability. They compared various methods of rating the well-formedness, and found that the probability of the worst part is not, in fact, the best predictor of acceptability. Coleman & Pierrehumbert claim that their results from gathering statistical data on acceptability show that the unacceptability (due to grammatical violations) of parts of words can be improved upon if the other parts of the words in which they occur are well-formed, and found in the lexicon with high frequency. For instance, in their study, an illegal form, such as /m.ɹupeɪʃn/, was rated better than a legal form, such as /splɛtsak/. This type of result suggests that the zero probability of a sub part (e.g. /m.ɹu/ in /m.ɹupeɪʃn/) is not enough to reject the non-word. Similarly, forms that have no constraint violations can be rated lower than an illegal form, due to the low frequency of other constituents' parts (e.g., /splɛtsak/). In fact, /fɪŋkslɔp/ was deemed completely unacceptable (and worse than /splɛtsak/), in spite of the well-formedness of its subparts (i.e., it has a higher probability than zero, which means that it is more probable than /m.ɹupeɪʃn/).

This model is based on the claim that it is the likelihood of each constituent (where constituency of segments refers to their constituency within a syllable) that contributes to the acceptability rating of a novel form. The likelihood of each constituent is determined by its prosodic position within a word. The results from Coleman and Pierrehumbert (1997) show that phonotactic well-formedness is correlated with the probabilistic measures that consider log word probability. In other words, they report findings contrary to an approach in which a single violation of any highly ranked constraint in the grammar would determine the evaluation of a non-word, but consistent with a stochastic model of the phonological grammar. The model developed by Coleman & Pierrehumbert, however, employs a rather rudimentary grammatical model, based on parsing words into syllables with onsets and rhymes as unanalyzed strings. While this model does not offer a complete phonological analysis of acceptability judgments, it is able to capture the fact that phonotactic judgment is gradient, as opposed to categorical. Therefore, in the current study this model (henceforth, the C&P model) was employed as an approximation of speakers' knowledge of grammatical probabilities.

In order to determine the probability of segments in relation to their prosodic positions, a corpus of English words was parsed based on the C&P model. The English corpus used in this study was an online Carnegie Mellon University dictionary (a pronunciation dictionary for North American English found at <http://www.speech.cs.cmu.edu/cgi-bin/cmudict>) with over 60,000 entries. All compounds, contractions, abbreviations, and affixes were removed. The corpus was parsed into onsets, nuclei, and codas.

Modeling after C&P meant that segment or segment sequences were the *fillers* that could occupy a *role* depending on their position in the structure. The fillers were determined empirically, based on parsing of the English corpus. The roles were syllable structures based on three parameters: 1) syllabic constituency, either onset or rime; 2) the presence, or absence, of stress; and 3) the position of the structure with respect to word edges. The following table summarizes the roles that were adapted from the C&P model:

<b>Syllabic constituent</b>	Onset   Rime
<b>Presence of stress</b>	Strong   Weak
<b>Location relative to word edge</b>	Initial (and not final)   Final (and not initial)   Initial & Final (monosyllables)

**Table 1 – Summary of the role parameters used in parsing an English corpus**

According to the grammatical model we are using, the number of times a particular filler (F) appears in a particular role (R) and the total of available roles (i.e., the number of times all fillers

appears in each role) must be computed. Next, to compute the probability (p) of having the filler in the role (R), the number of observations has to be divided by the number of possible positions:

$$p(\text{F in R}) = \frac{\text{\# of times F is in position R}}{\text{\# of possible position Rs}}$$

The probability of each novel string (p(w)) was based on the product of the probability of the constituents (p(F in R)). The probability of each constituent was based on the probability score it received after parsing the online dictionary. This score (i.e. the product of the log of frequencies) will be referred to hereafter as PLog. A corpus of all possible monosyllabic words in English<sup>5</sup> that contained close to 20,000 pseudo-words was used to extract the stimuli.<sup>6</sup> A probability score (PLog) for each entry in this corpus (referred to as stimulus corpus) was calculated and was used to classify the entries as Hi-PLog and Low-PLog. An entry in Hi-PLog category meant that the item had a high probability score.

*Assessing the lexical mechanism.* In order to find the pseudo-words in a desired lexical neighborhood, a set of measures was used based on the Generalized Neighborhood Model (GNM) developed by Bailey & Hahn (2001). As discussed earlier, this model assesses a neighbor based on the cost of substitution of one phoneme for another where the cost is computed according to phoneme similarity. The Generalized Neighborhood Model was implemented directly, using software written by Adam Albright of M.I.T. The model used in this study performs edit distance measurements based on the GNM. However, it only considers neighbors that are one phoneme away. Therefore, each entry on the stimulus corpus received a lexical similarity score (SIM) that reported its similarity to the words in the CMU corpus. Based on the lexical similarity score (SIM), entries were classified as Hi-SIM and Low-SIM. An entry in Hi-SIM category meant that the item had a high lexical similarity score.

The difficulty in determining the independent effects of grammatical probability and lexical similarity lies in the following. High probability segments are found in many words and a word that contains high probability segments tends to have many words in the lexicon that are phonologically similar to that word. As a result, words with high probability segments tend to be in dense neighborhoods. This means that when we are offering either effect as an explanation for speed and/or accuracy in word processing or in phonotactic well-formedness judgments, we have to first tease apart the effect of probability from the effect of density in the experimental stimuli. To this end, in the two SIM categories (Hi-SIM and Lo-SIM) in the stimulus corpus, items could be selected that belonged to either Hi-PLog or Lo-PLog categories. This meant that a stimulus could be selected such that it had high probability score (Hi-PLog) but a low lexical similarity score (Lo-SIM).

The possibility of both effects (grammatical and lexical) rendering similar judgments (i.e., an item having a high score in both categories) or different judgments (i.e., an item having high score in one category and low score in the other) allowed for four logical possibilities in categorizing a novel form depending on the type of contributions from the two components: 1) Hi-PLog & Hi-SIM; 2) Hi-PLog & Lo-SIM; 3) Lo-PLog & Hi-SIM; and 4) Lo-PLog & Lo-SIM.

In addition, stimuli were included that contained an outright phonotactic violation. A set of 500 phonotactically illegal non-words were used as the starting point in selecting the experimental stimuli in this category. The violations were determined based on the phonological restrictions in English reported by Hammond (1999). Items in this subcategory did not originate from the same corpus as the other stimuli. In these conditions, one constituent violated a phonotactic restriction, while the other constituent was a high probability constituent. The items in the 500-word corpus were classified as Lo-SIM or Hi-SIM based on their lexical similarity score.

*Material.* The stimuli comprised 84 monosyllable non-words. Monosyllables were used in this study in order to remove the location of stress as a factor in determining the acceptability rating of the

<sup>5</sup> The list was generously provided by Mike Hammond (University of Arizona).

<sup>6</sup> This corpus contained forms that could be rendered as acceptable if they were analyzed as bi-morphemic. For example, /zd/ and /spt/ appear in codas in English only in suffixed forms. In order to avoid the problem of participants' rating a form higher due to its morphological composition, all the forms that contained codas that could only be analyzed as suffixed were removed from the stimulus corpus.

stimuli. The following table summarizes all experimental conditions. 12 items were selected for each category:

<b>Positional Probability</b>			
<i>Lexical Similarity</i>	<b>High Plog (HP)</b>	<b>Low PLog (LP)</b>	<b>Violation (V)</b>
<i>High Sim (HS)</i>	pæz, rʌk, bis	zek, θæɪ, kreɪz	ritk, pɛrð, krɪ
<i>Low Sim (LS)</i>	flɪst, mæmp, strɪn	bjust, glɑrm, smʌsp	smaɪgl, froɪsp, plɪθf

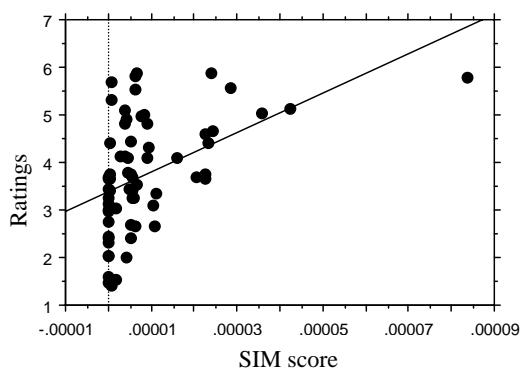
**Table 2 – Summary of the conditions used in the well-formedness judgment task with example words**

The stimuli for this experiment were digitally recorded by a female trained phonetician who is a native speaker of English. The speaker repeated every item three times, and using PRAAT (Boersma & Weenink), the third token was cut and stored.

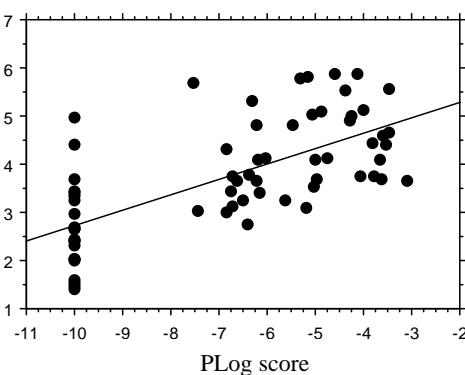
*Procedure.* The participants heard every stimulus twice via headphones, while a string of letters (a close orthographic approximation of the stimulus) appeared on a computer screen in front of them. The participants were then asked to rate the “typicality” of the novel form on a scale from 1 (“completely normal, this would make a fine English word”) to 7 (“completely bizarre, this is impossible as an English word”). Furthermore, they were instructed to ignore the spelling in their scoring. The order of presentation of stimuli was randomized for each participant. The participants’ judgments were recorded with Psyscope software (Cohen, MacWhinney, Flatt, Provost, 1993).

## 2.1. Discussion of Results

This experiment was designed to examine the effects of grammatical probability and lexical similarity independently. The results show that grammatical probability has the main effect in the well-formedness ratings given by participants. A multiple regression analysis showed that the effect of grammar was stronger ( $p < .001$ ) than the effect of lexical similarity ( $p \sim 0.05$ ). As the chart below shows, the correlation between PLog and the ratings was stronger ( $r = 0.67$ ) than the correlation between SIM and the ratings ( $r = 0.46$ ):



**Figure 1 – SIM vs. Ratings plot**



**Figure 2 – PLog vs. Ratings Plot**

This result contrasts with the one reported by Bailey & Hahn (2001) who found a greater influence of lexical similarity than phonotactic probability. On the other hand, the stimulus set used by Bailey & Hahn included both real words and novel words. The speculation was that the inclusion of real words skewed the results towards a stronger lexical effect. Examining the speed of processing of real words and non-words, Vitevitch and Luce (1998, 1999) have argued that the effects of phonotactics emerge in processing of non-words and the effects of neighborhood density emerge in

processing of real words. Therefore, we predicted that without any real words in the stimulus set no item would initiate a lexical search. On the other hand, the presence of real words would indeed cause a lexical search in order to access a single lexical unit. To confirm this hypothesis, experiment 2 was carried out.

### 3. Experiment 2 – Novel Words and Real Words

*Participants.* Participants were 24 undergraduates from the University of California, Los Angeles. The students participated in the experiment as part of their Introduction to Linguistics course. The instructions given to the participants and the method of data collection were the same as in Experiment 1.

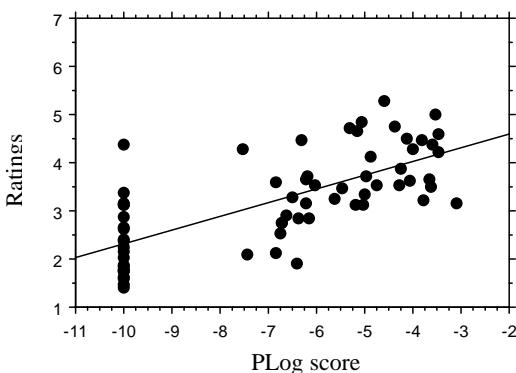
*Materials.* In this experiment both novel and real words were presented to the participants. The novel forms were the same as in Experiment 1. The real words were chosen to fall into the same initial four conditions as the novel forms (since the violation cases were not a possibility):

<b>Positional Probability</b>			
<i>Lexical Similarity</i>	<b>High PLog (HP)</b>	<b>Low PLog (LP)</b>	<b>Violation (V)</b>
<i>High Sim (HS)</i>	<i>rise</i>	<i>crush</i>	<i>NA</i>
<i>Low Sim (LS)</i>	<i>chop</i>	<i>swamp</i>	<i>NA</i>

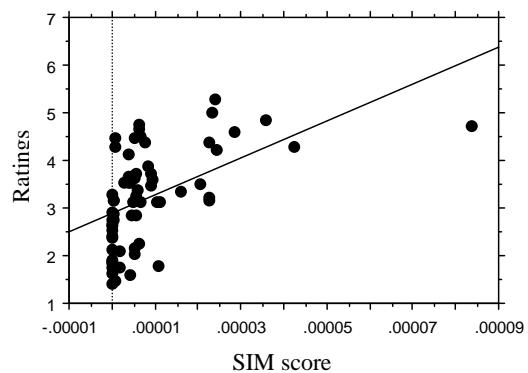
**Table 3 – The conditions for the real word stimuli**

#### 3.1. Discussion of Results

Experiment 2 was designed to determine whether the balance between grammatical probability and lexical similarity that was observed in experiment 1 could be shifted. The findings show that inclusion of real words in the stimulus set results in the lexical similarity emerging as a main effect. A multiple regression analysis revealed that there were two main effects: a grammatical effect ( $p < .001$ ) and an analogical effect ( $p < .001$ ). As expected, correlation between the ratings and SIM scores improved for the second experiment ( $r = .51$ ). Moreover, the correlation between PLog and ratings also slightly improved in the second experiment ( $r = .70$ ):

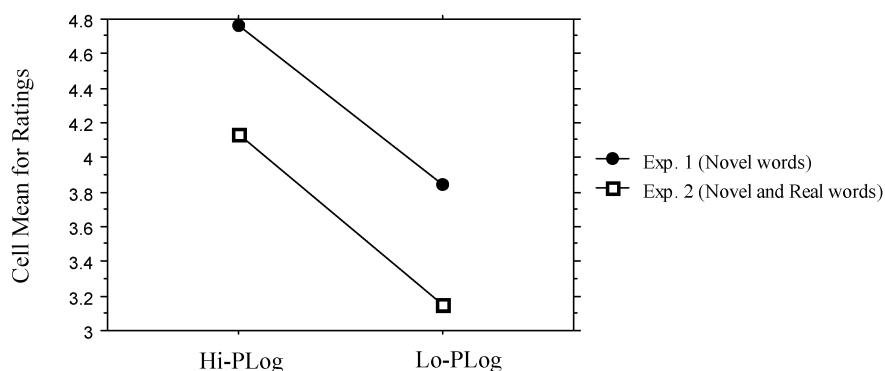


**Figure 3 – PLog Vs. Ratings Plot**



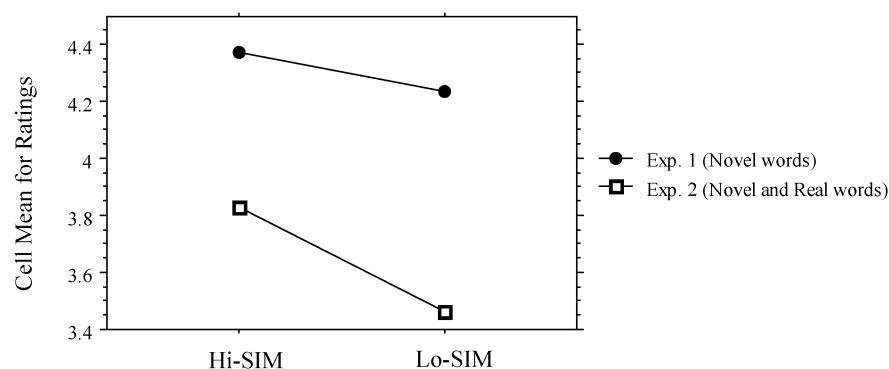
**Figure 4 – SIM Vs. Ratings Plot**

Comparing the results of the two experiments revealed that the effect of grammatical scores (PLog) was consistent for both groups. Both subject groups rated the Lo-PLog items lower than the Hi-PLog items. While the subjects who saw real words in the stimuli set consistently rated the novel forms lower, the effect was similar in both groups, as the chart below illustrates:



**Figure 5 – The responses from the two experimental groups for Hi-Probability and Low-Probability Stimuli**

On the other hand, the effect of lexical similarity was greater for the experimental group who rated both the novel forms and the real forms:



**Figure 6 - The responses from the two experimental groups for Hi-Similarity and Low- Similarity Stimuli**

#### 4. General Discussion

The research reported here examines the effects of grammatical probability and lexical similarity in well-formedness judgments. The issue of whether these two mechanisms are distinct components of linguistic knowledge, or whether grammatical probability is simply an implicit part of the lexicon, has been addressed from a variety of psycholinguistic perspectives (Trieman et al., 2000; Vitevitch & Luce, 1998; Bailey & Hahn, 2001; McClelland & Elman, 1986). The difficulty in addressing the issue partly arises because grammatical probability and lexical similarity are often confounded. The experiments reported in this paper are designed to allow for independent manipulation of the two factors, grammatical probability and lexical similarity. While the results confirm the conclusion by Bailey and Hahn (2001) that there are two unique mechanisms at work, they do not conform in two aspects.

First, the effect of lexical analogy, when it has a main effect on the ratings (in experiment 2), is not stronger than grammatical probability. The reported strength of grammatical probability might seem in conflict with the results reported by Bailey and Hahn, who found a greater effect of lexical analogy than phonotactic probability. However, the stimulus set used in their study comprised items that always had a real-word neighbor. This choice might have caused the effect of lexical analogy to be magnified as opposed to the grammatical probability effect. Nevertheless, the current findings confirm

the conclusion of Frisch et al. (2000), who found phonotactic probability to be more effective than neighborhood density in predicting well-formedness judgments because it is found that, in the presence of grammatical probability *and* lexical similarity effects, grammatical probability is a better predictor of well-formedness judgments.

Second, the difference between the ratings given by the two groups (Experiment 1 and Experiment 2) shows that the effect of lexical analogy can emerge as the result of the existing lexical items in the stimuli set. The stimuli in Experiment 1 consisted of items that do not instigate a direct access to a specific lexical item. Inclusion of real words in the experimental stimuli in Experiment 2 creates an implicit lexical decision task in which the participants would be regularly searching their lexicon during the well-formedness rating task. It could be that the effects of lexical similarity are simply a by-product of the lexical access process. This is in accordance with the claim of Vitevitch and Luce (1998) that while the processing of real words is dominated by influences from the lexicon, the effect of phonotactics is the dominant factor in the processing of non-words. The current study finds that the effect of grammatical probability is invariant to the experimental design, but the presence, or absence, of lexical similarity effects is predictable based on the experimental stimuli.

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