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A program for phonotactic theory*

Kyle Gorman
University of Pennsylvania

This study has two distinct, complementary aims. The first is to outline the empirical scope of *phonotactic theory*, the theory of speakers' knowledge of possible and impossible (or likely and unlikely) words, and to put forth a simple hypothesis for the architectural underlying this knowledge. The second is to argue that the increasingly popular view of phonotactics and phonotactic learning as a type of statistical inference is incapable of accounting for the facts of this domain.

1 The empirical scope of phonotactic theory

1.1 Wordlikeness judgements

As Halle (1962) and Chomsky & Halle (1965) note, speakers readily distinguish between a well-formed and an ill-formed word, neither of which is an actual word. Neither [blɪk] *blick* nor [bnɪk] *bnick* is a word of English, yet English speakers immediately report that only the former is "possible". While this fact has no clear role to play in language production, there can be no question that it is part of speakers' knowledge. Elicited in a controlled fashion, these *wordlikeness judgements* are perhaps the most important (and least controversial) source of phonotactic evidence.

1.2 Word production and recognition

Speakers have difficulty producing (e.g., Davidson 2006, 2010, Gallagher in press, Rose & King 2007, Vitevitch *et al.* 1997) and perceiving (e.g., Dupoux *et al.* 1999, Kabak & Idsardi 2007, Massaro & Cohen 1983) phonotactically illicit nonce words.

In English, sequences of adjacent obstruents which do not also agree in voice (e.g., *a*[b.s]*inth*) are quite rare within a word, and therefore a hetero-voiced obstruent cluster is a clue to the presence of a word boundary in running speech. Infants (Mattys & Jusczyk 2001) and adults (McQueen 1998) are both thought to use this heuristic for word recognition in experimental settings.[1]

Berent *et al.* (2001) and Coetzee (2008) claim that non-word recognition latencies in lexical decision tasks reflect speakers' phonotactic knowledge, the hypothesis being that a phonotactically illicit nonce word will be rejected more quickly than a well-formed nonce word. However, phonotactic constraints are often confounded with independent predictors of lexical decision latencies. For instance, Coetzee (2008) finds that English speakers recognize [sp…p] and [sk…k] nonce

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[1] It is important to note that word segmentation heuristics are to some degree independent of the mechanisms implicated by wordlikeness judgements. Whatever the locus of [bnɪk]'s ill-formedness, for example, no segmentation into multiple words or morphs renders it a well-formed sequence.

monosyllables faster than [st…t] nonce monosyllables in an auditory lexical decision task. Coetzee attributes this to ad hoc phonotactic constraints against the former sequences, but another explanation is available. Even at an early stage of recognition, [stVt] is distinguished from [spVp, skVk] by its higher *cohort density*: there are far more words starting with initial [st] than with [sp] or [sk]. High cohort density is known to inhibit auditory processing of non-words (e.g., Marslen-Wilson & Welsh 1978) and this alone could account for the difference in processing time.

1.3 Loanword adaptation

Loanword adaptation may provide further evidence for the psychological reality of phonotactic knowledge. In Desano (Kaye 1974), for instance, all underlying representations (URs) are either totally oral (e.g., [yaha] 'to hear') or totally nasal (e.g., [ñãhã] 'to enter'), and loanwords are made to conform to this generalization: Portuguese *martelo* 'hammer' is adapted as [barateru] and Spanish *naranja* 'orange' as [nãnãnã]. Presumably, some component of the synchronic grammar is both responsible for the restriction on native vocabulary and its extension to loanwords.

There are many other cases, however, where such restrictions are not extended to loanwords (e.g., Clements & Sezer 1982, Davidson & Noyer 1997:75, Itô & Mester 1995ab, Peperkamp 2005, Shibatani 1973:95, Ussishkin & Wedel 2003, Vogt 1954; additional examples can be found below). Given our limited understanding of loanword adaptation at present, it may be premature to regard this inertness as strong evidence against the constraints in question, though it may be a useful diagnostic.

1.4 Lexical statistics

Statistical patterns in lexical entries are often taken as phonotactic evidence; the status of this data will be considered in §3 below.

2 The grammatical basis of phonotactic knowledge

With the primary evidence for phonotactic theory now established, it is possible to consider the grammatical architecture that underlies this knowledge.

2.1 The insufficiency of morpheme structure constraints

Early generative phonologists posited that phonotactic ill-formedness derives solely from *morpheme structure constraints*, restrictions on underlying representations (e.g., Chomsky & Halle 1965, 1968, Halle 1962). These come in two types (Stanley 1967). *Segment structure constraints* impose restrictions on the underlying segment inventory: e.g., in Russian, voicing is contrastive for all obstruents except /ts, tʃ, x/ (Halle 1959:22): [dz, dʒ, ɣ] appear in surface, but not underlying, representations. *Sequence structure constraints* apply to underlying sequences; an example adapted from Chomsky & Halle (1965:100) is given below.

(1) An English MSC: $[+\text{Cons}] \longrightarrow [+\text{Liquid}] \;/\; \# \begin{bmatrix} +\text{Cons} \\ -\text{Strid} \end{bmatrix} \_$

This sequence structure constraint specifies the second of a sequence of word-initial consonants as a liquid, so as to preclude underlying /bnɪk/, for example. However, Shibatani (1973) argues that not all wordlikeness contrasts can be expressed as constraints on URs. In German, for instance, obstruent voicing is contrastive, but neutralizes finally: e.g., [gʀa:t]-[gʀa:tə] 'ridge(s)' vs. [gʀa:t]-[gʀa:də] 'degree(s)'. By hypothesis, the latter root ends in /d/, so the constraint against final voiced obstruents is specific to surface representations. Yet, Shibatani claims, German speakers judge voiced obstruent-final nonce words to be ill-formed.[2]

2.2 The duplication problem

Whereas Shibatani argues that morpheme structure constraints are insufficient to account for speakers' phonotactic knowledge, other authors observe the tendency for structural descriptions of phonological processes to reappear among the morpheme structure constraints on the same language (e.g., Hale 1965:297, Kisseberth 1970, Postal 1968:212f.). In Russian, for instance, a process of anticipatory assimilation ensures that derived clusters of obstruents agree in voice.[3]

(2) Russian voice assimilation alternations (adapted from Halle 1959:22f.):

a.	[ˈʒedʒbɨ]	'were one to burn'	[ˈʒetʃʲi]	'should one burn?'
b.	[ˈmogbɨ]	'were (he) getting wet'	[ˈmoklʲi]	'was (he) getting wet?'

Similarly, underlying voicing is "nondistinctive in all but the last member of a cluster of obstruents" (Anderson 1974:283). Despite their tantalizing similarity, these two facts are treated as distinct under the traditional view.

The alternation facts are, in some prior sense, more privileged. It is possible to deny that the restrictions on underlying representations are psychologically real since they are "computationally inert and thus irrelevant to the input-output mapping that the grammar is responsible for" (Hale & Reiss 2008:18). On the other hand, voice assimilation is essential to a concise statement of the surface forms of Russian. Dell (1973:205f.) and Stampe (1973:28f.) suggest that the problem is that the distinction between constraints on URs and alternations is unmotivated, and that these different levels are related by a principle now known as *Stampean occultation* (Prince & Smolensky 1993:54).[4] In a language like Russian, in which surface obstruent clusters exceptionlessly agree in voicing, there is simply no reason for the

[2] Voicing of final obstruents is usually lost in German loanword adaptation: e.g., English *hot dog* becomes [hɑt dɔk] (Ussishkin & Wedel 2003:506).

[3] For sake of discussion, the complex behavior of [v] is ignored here.

[4] This is quite similar to the original argument of Halle (1959) regarding Russian obstruent voice assimilation. The principle of biuniquness in vogue at that time demands a distinction between neutralizing (morphophonemic) and non-neutralizing (phonemic) processes. In Russian, obstruents participate in voice assimilation whether this neutralizes a phonemic distinction (2a) or not (2b): recall that there is no underlying /dʒ/ in Russian. Halle argues that biuniqueness (and the distinction between the morphophonemic and phonemic levels that follows from it) entails "a significant increase in the complexity of the representation" (24). While Anderson (2000) sketches an analysis which preserves biuniqueness without morphophonemic/phonemic duplication, this requires further contested assumptions—contrastive underspecification (against which, see Steriade 1995) and a Duke-of-York derivation—consistent with Halle's claim that biuniquness imposes unnecessary complexities.

language acquisition device to posit underlying hetero-voiced obstruent clusters: obstruent voice assimilation "occults" underlying */kb/, for instance. Were such an underlying form posited, it would surface as [gb] in all contexts.[5] Unless there is some alternation (e.g., epenthesis) which would reveal /kb/, there is simply no reason to bother to set up this abstract underlying representation. In an architecture like Lexical Phonology, it is even possible to apply a process to individual underlying representations (i.e., at the "lexical level") so as to derive non-surface-true constraints. Consequently, MSCs are otiose.

Even constraints on underlying representations may be elegantly described in terms of non-contrastive prosodic structures like the syllable (e.g., Hooper 1973, Kahn 1976).[6] For instance, as Haugen (1956) notes, many restrictions on medial consonant clusters follow from the requirement that word-medial consonant clusters be decomposable into a (possibly null) well-formed coda and a well-formed onset. Assuming Stampean occultation, syllable structure need not be underlyingly present to derive this constraint: an underlying representation containing a cluster which could not be decomposed in this fashion would be occulted. Similarly, initial /bn/ in English is occulted by restrictions on prosodic parsing, ruling out [bnɪk] (e.g., Wolf & McCarthy 2009:19f.)

2.3 Static constraints

If MSCs are epiphenomenal, there are no substantive constraints on underlying representations which are not derived from phonological processes. This principle—*no static phonotactic constraints*—has interesting ramifications for evaluating certain competing phonological analyses. Consider Sanskrit aspiration alternations such as *bodhati-bhotsyati* 'he wakes-he will wake'. According to one analysis, which has a precedent in Pāṇini, the root /budh/ undergoes a process shifting aspiration leftward in certain contexts (e.g., Borowsky & Mester 1983, Hoenigswald 1965, Kaye & Lowenstamm 1985, Sag 1974, 1976, Schindler 1976, Stemberger 1980, Whitney 1889:§141f.). An alternative analysis posits an underlying /bhudh/ and a process of aspirate dissimilation, a synchronic analogue of Grassman's Law (e.g., Anderson 1970, Hoard 1975, Kiparsky 1965:§3.2, Phelps & Brame 1973, Phelps 1975, Zwicky 1965:109f.). Under the latter analysis, multiple surface aspirates (e.g., hypothetical **bhodhati*) are phonotactically marked; the former account makes no such prediction. If there are no static phonotactic constraints, psycholinguistic tasks could (in theory) be used to decide between these two accounts.

[5] *Lexicon Optimization* (Prince & Smolensky 1993:209) implements a form of Stampean occultation notable in that it projects all non-alternating surface segments directly into URs. For instance, in English, Lexicon Optimization demands underlying /ŋ/ in words like *bank*, even though [ŋ] can be analyzed as an allophone of /n/ before velar consonants (e.g., Borowsky 1986, 65f.:65f.), simplifying the phoneme inventory. However, this is not core to Dell and Stampe's insight about the relationship between surface and underlying sequence structure restrictions. For instance, the hypothetical /bæŋk/ posited by Lexicon Optimization could be revised to /bænk/, and take a free ride on the process of nasal place assimilation found elsewhere in English. Indeed, this seems desirable, since Lexicon Optimization forces a duplication between underlying and surface constraints: for instance, [ŋ] does not appear word-initially and English speakers have considerable difficulty producing it in this position (Rusaw & Cole 2009). The allophonic analysis of [ŋ] predicts this fact, since there is no way to derive the [ŋ] allophone in onset position.

[6] See Blevins 1995 on the claim that syllable structure is universally non-contrastive.

3 A critique of probabilistic phonotactics

As noted above, it is the null hypothesis that any well-formed coda and well-formed onset can form a medial consonant cluster. In English, [s] is both a licit coda and onset (e.g., *ma*[s.t]*er*, *can*[n.s]*el*), but there are no *[s.s] clusters: in fact, none of the 6,619 "monomorphemic" words in the CELEX database contains a geminate. According to the Fisher exact test, this gap is unlikely to arise by chance.

(3) English medial geminate clusters in English (Gorman in press c):

	attested	unattested	saturation	*p*-value
Geminate clusters	0	104	0%	1.2×10^{-10}
Other CC^{+} clusters	173	643	21%	

Stampean occultation provides a natural explanation for this gap, since degemination is characteristic of "level I" morphology: it is found in "semi-weak" past tense forms (e.g., *bend-ben*[t], *build-buil*[t]), deadjectival derivatives (e.g., *free-free*[l]*y* vs. *full-fu*[l]*y*), and Latinate prefixes (Borowsky 1986:102).

Not all exceptionless restrictions represent "structural" gaps according to statistical criteria. For instance, Pierrehumbert (1994:176) notes that English lacks word-medial consonant clusters with identical first and third elements in simplex words, though such clusters occur in forms consisting of a Latinate prefix and bound stem (e.g., *e*[ks.kl]*ude*). Unlike the absence of geminates, Stampean occultation provides no explanation for this gap: this could only be a static phonotactic constraint. While there are no apparent exceptions to this constraint, the zero frequency of "ABA" clusters is not surprising considering the rarity of medial CCC clusters in English.

(4) English medial ABA clusters (Gorman in press c):

	attested	unattested	saturation	*p*-value
ABA clusters	0	25	0%	.250
other CCC clusters	47	512	8%	

This method can be used to distinguish *structural* from *accidental* phonotactic gaps, the latter representing those gaps that may have arisen by chance, without any antecedent cause. It is commonly assumed that non-accidental phonotactic patterns "directly determine the mental representation of the phonotactic constraints" (Frisch *et al.* 2004:180; for other examples, see Alderete & Bradshaw 2013, Anttila 2008, Berkley 1994ab, Buckley 1997, Coetzee 2008, Coetzee & Pater 2008, Elmedlaoui 1995, Graff & Jaeger 2012, Hayes & Wilson 2008, Kawahara *et al.* 2006, Kinney 2005, MacEachern 1999, Martin 2011, McCarthy 1988, Mester 1988, Miller-Ockhuizen 2003, 1995, Pierrehumbert 1993, Pozdniakov & Segerer 2007, Saporta 1955, Saporta & Olson 1958, Yip 1989, Vogt 1954). For instance, Brown writes:

> … the patterns outlined above are statistically significant. Given this, it stands that these sound patterns should be explained by some linguistic mechanism. (Brown 2010:48)

It would be a result of great interest were it shown that statistical significance is both necessary and sufficient to identify linguistic generalizations which are internalized by speakers, but there is no reason to grant this assumption with respect to phonotactic knowledge. Nothing requires that the antecedent cause of a statistically reliable lexical tendency is grammatical: in fact as discussed below, there are reasons to suspect that many static phonotactic constraints identified in this manner have no synchronic reality at all.

3.1 Static constraints and the role of diachrony

By hypothesis, the phonological component may impose constraints on sound segments and sequences at various levels, including underlying representations (§2.2). Beyond this, the null hypothesis is that there is no grammatical explanation for underlying representations a language chooses to instantiate. It is a practical necessity that numerous well-formed underlying representations will be uninstantiated, as the lexicon is finite but there are an infinitude of possible URs. The synchronic grammar cannot reasonably be expected to account for all non-existent underlying representations: for instance, English phonology has nothing informative to say about the absence of */blɪk/ (cf. *flick*, *brick*, *block*, *blink*).

This much seems uncontroversial. However, even when a phonotactic generalization over underlying representations can be given a phonological characterization, there is a plausible alternative to the assumption that it is part of the synchronic grammar: the generalization may be the result of now-complete diachronic change. Since sound changes operate over the same representations as synchronic processes, this provides an explanation for the fact that the generalization can be characterized in phonological terms. Further, it shows that the structural nature of a gap is not pertinent to determining whether the constraint is synchronically real.

Saussure (1916) presents an example of phonotactic underrepresentation caused by sound change. With only sporadic exceptions, Old Latin intervocalic *s* undergoes a conditioned phonemic merger with *r*. This has two consequences. First, underlying intervocalic *s* is underrepresented in Latin. Second, it introduces many *s*-*r* alternations: e.g., *honōs*-*honōris* ‘honor’. The traditional analysis treats *r* as the intervocalic allophone of /s/, and derives *honōris* from underlying /hono:s-is/.

(5) Rhotacism: $\mathrm{s} \longrightarrow \mathrm{r} \;/\; [+\mathrm{Voc}] \_\_ [+\mathrm{Voc}]$

However, subsequent sound changes (Baldi 1994, Safarewicz 1932), most notably the degemination of Old Latin *ss* before diphthongs and long monophthongs (e.g., *caussa* > *causa* ‘cause’), introduce numerous exceptions to Rhotacism. In Classical Latin, intervocalic *s* is found root-internally (*asellus* ‘donkey’, *casa* ‘hut’), in environments derived by inflectional suffixes (*uās*-*uāsis* ‘vase’, *uisēre* ‘to view’), prefixation (*dēsecāre* ‘to cut off’; cf. *dē* ‘from’, *secāre* ‘to cut’), compounding (*olusātrum* ‘parsnip’; cf. *olus* ‘vegetable’, *ātrum* ‘black’), and denominal adjective formation (*uentōsus* ‘windy’; cf. *uentus* ‘wind’), and is tolerated in nativized loanwords from Celtic (*omāsum* ‘tripe’), Germanic (*glaesum* ‘amber’), and Greek (*basis* ‘pedestal’). These facts lead Saussure to conclude that Rhotacism is no longer “inhérente à la nature de la langue” (202). While some of the apparent exceptions may be the result of

opaque phonological application (Heslin 1987)—an explanation not yet available in Saussure's time—any formulation of rhotacization will admit nearly as many lexical exceptions as there are roots exhibiting *s*-*r* alternations (Gorman in press b). The accumulation of exceptions provides further evidence for Rhotacism's obsolescence. Any synchronic account of the underrepresentation of intervocalic *s* must confront the unproductive nature of the proximate explanation for this tendency.

Other cases show more clearly that statistically identified constraints may have no cognitive reality. For instance, most instances of Modern English [ʃ] derive from Old English [sk] (e.g., *fisc* 'fish') via sound change. Since Old English does not permit long vowels before complex codas, [ʃ] is still rarely preceded by long vowels in word-final syllables compared to similar segments like [s].[7]

(6) Vowel length before word-final alveolar fricatives in English:

	{ɪ, ɛ, æ, ʌ, ʊ}__#	{i, e, ɑ, ɔ, u}__#	% long	*p*-value
__ʃ#	78	9	8%	.026
__s#	410	107	16%	

As can be seen, long vowels are twice as common before [s] as before [ʃ], a significant generalization according to the Fisher exact test. Similarly, Hayes & White (2013) report that this constraint is discovered by the Hayes & Wilson (2008) phonotactic learning model, which uses a related statistical criterion to identify constraints. Despite this, Iverson & Salmons (2005) label the constraint on long vowels before [ʃ] as "phonologically accidental" since a millennium of coinages (e.g., *posh*) and loanwords (e.g., *douche*) disregard this generalization. And, Hayes & White (2013) provide evidence that this constraint goes unlearned: they find that a variant of this restriction has little to no effect on speakers' wordlikeness judgements.

3.2 Static constraints and the role of naturalness

To account for the cases like the one above, Hayes & White (2013) propose that speakers are biased in favor of "natural generalizations" in probabilistic phonotactic learning.[8] Labial Attraction in Turkish provides an excellent test case.

Lees (1966:35) notes the tendency of Turkish high back vowels to be round after *a*-labial consonant sequences, and formalizes this as a phonological process.

(7) Labial Attraction: $\begin{bmatrix}-\text{Cons}\\+\text{Back}\\+\text{High}\end{bmatrix} \longrightarrow [+\text{Rnd}] \;/\; \alpha\, C_0 \begin{bmatrix}+\text{Lab}\\+\text{Cons}\end{bmatrix} C_0 \_\_$

Some roots conforming to this restriction are *çapul* 'raid', *sabur* 'patient', *şaful* 'wooden honey tub', *avuç* 'palm of hand', *samur* 'sable'. However, this general-

[7] This sample is drawn from the CMU pronunciation dictionary, filtered by excluding words with a token frequency of less than 1 per million words in the SUBTLEX-US frequency norms. Less restrictive samples give similar results.

[8] Hayes & White do not provide an operational definition of "naturalness", so it is difficult to evaluate their results or to determine whether naturalness is applied in an ad hoc (or post hoc) fashion.

ization gives rise to no alternations (though Inkelas *et al.* 1997:394 suggest it may have at one point in time): for example, the genitive singular of *sap* 'stalk' is *sapın*, not **sapun*. Both Lees (ibid.) and Zimmer (1969) cite roots which do not conform to Labial Attraction (e.g., *tavır* 'mode') but agree that they are surprisingly rare. Clements & Sezer (1982) disputes this, writing:

> …decisive evidence against a rule of Labial Attraction is the existence of a further, much larger set of roots containing /…aCu…/ sequences in which the intervening consonant or consonant cluster does not contain a labial… We conclude that there is no systematic restriction on the set of consonants that may occur medially in roots of the form /…aCu…/. (Clements & Sezer 1982:225)

This claim can be evaluated with the Fisher exact test. Let P denote a sequence of one or more consonants containing at least one labial, and let T denote a sequence of one or more consonants, all non-labial. The null hypothesis is that *a*P*u* sequences, which conform to Labial Attraction, are no more likely than *a*T*u* sequences. The counts are shown below. Whereas the sequence *a*P*u* is twice as likely as *a*P*ı*, the sequence *a*T*u* is many times less likely than *a*T*ı*. Contrary to Clements & Sezer, Labial Attraction encodes a statistically reliable generalization about underlying representations. It still remains an open question what accounts for this tendency, however.

(8) Type frequencies in the Turkish Electronic Living Lexicon (Inkelas *et al.* 2000):

	*a*__*u*	*a*__*ı*	% *ı*	*p*-value
*a*P__	124	57	31%	1.02×10^{-36}
*a*T__	136	590	81%	

Zimmer (1969) investigates whether speakers have internalized any form of Labial Attraction using a wordlikeness task. Native speakers are presented a pair of two nonce words, differing in only whether they obey or violate Labial Attraction, and simply identify the nonce word they judge to be more Turkish-like.[9] Only one of the five pairs shows the expected preference: *tafuz* is favored over *tafız*, 21–11. Statistical analysis of Zimmer's results reveals no overall bias corresponding to Labial Attraction (two-tailed binomial test, $p = .192$): it seems that Labial Attraction, while statistically reliable, goes unlearned.[10] Becker *et al.* cite this as evidence that naturalness constrains phonotactic learning.

[9]This paired judgement task may strike some readers as primitive. In fact such tests have more statistical power than unpaired judgment tasks (e.g., Gigerenzer & Richter 1990), since there is little chance that any contrast between the phonotactically licit and illicit members of an otherwise-identical nonce words pair is caused by an omitted variable.

[10]Itô & Mester (1995a) claim that Labial Attraction holds only over the native vocabulary. This is a potential confound for Zimmer's experiment, since it is not implausible that speakers in Zimmer's study would treat nonce words much like loanwords. However, Inkelas *et al.* (2001) find that foreign words are more likely to conform to Labial Attraction than native words, contrary to Itô & Mester's claim. One possible explanation is that many of the languages in contact with Turkish lack the *ı* needed to contribute exceptions to this generaliation.

> This is clearly a complex and somewhat unnatural phonotactic, both in terms of the nonlocality of environment and the conjunction of features from two distinct triggers, and it is therefore a welcome result that not all speakers readily encoded it into a generalizable constraint. (Becker *et al.* 2011:118)

If this is correct, it should be possible to show that a more "natural" variant of Labial Attraction is in fact reflected in wordlikeness judgements, assuming it too is statistically valid. A simpler variant is proposed by Inkelas *et al.* (2001:196).

(9) Labial Attraction′: $\begin{bmatrix} -\text{Cons} \\ +\text{Back} \\ +\text{High} \end{bmatrix} \longrightarrow [+\text{Rnd}] \; / \; \begin{bmatrix} +\text{Lab} \\ +\text{Cons} \end{bmatrix} \; \_\_$

The environment is now strictly local. Rounding of high vowels after labial consonants is also acoustically natural, as both are distinguished by low first and second formants. Finally, the rounding of a high back vowel after a labial consonant is widely attested (e.g., Vaux 1993). Furthermore, it is even more statistically reliable than Labial Attraction (Fisher exact test, $p = 6.98 \times 10^{-49}$). Since this reformulation targets a superset of Lees's original rule, it should be reflected in the paired rating task, but this does not obtain. This clearly shows that not all statistically reliable, "natural" phonotactic generalizations are learned.

In contrast, Zimmer finds that vowel harmony has a robust effect on wordlikeness preferences. The one detail that differentiates Labial Attraction and vowel harmony is that the former is related to no phonological process in Turkish, whereas the latter derives suffix allomorphy patterns, so this is consistent with the principle that speakers do not internalize static phonotactic constraints.

3.3 Phonotactics as gradient grammaticality

It has recently been claimed that speakers' intuitions of wordlikeness are inherently *gradient*, i.e., more granular than implied by a binary contrast between "possible" and "impossible" words (e.g., Albright 2009:9, Hayes & Wilson 2008:382, Shademan 2006:371). This is also the position of Chomsky & Halle (1968), who introduce a third nonce word [bznk], which they claim is even less English-like than [bnɪk]. Chomsky & Halle conclude that phonotactic theory should "make numerous other distinctions of this sort" (417).[11]

However, there are reasons to question the link between gradient wordlikeness judgements and gradient well-formedness models. First, Armstrong *et al.* (1983)

[11] It has been assumed so far that wordlikeness judgements depend on language-specific knowledge, as is the position of Chomsky & Halle (1965): "This distinction is, furthermore, not a matter of universal phonetics" (101). The forms [bnɪk] and [bznk] are not impossible in all languages: [bn] onsets are found in Moroccan Arabic (e.g., *bniqa* 'closet'), and Imdlawn Tashlhiyt Berber permits whole words consisting of a stop-fricative-nasal-stop sequence (e.g., [tzmt] 'it is stifling'; Dell & Elmedlaoui 1985:112). An alternative is to posit innate implicational universals to account for speakers' preferences among ill-formed nonce words (e.g., Berent *et al.* 2007). While space restrictions preclude further discussion of this hypothesis, it should be noted that this would considerably limit the scope of phonotactic learning as it is normally understood.

argue that many-valued scales induce intermediate ratings even when the concept in question is not gradable (e.g., "odd number"), and therefore are not pertinent to determining the gradient or categorical nature of a concept.

Research in gradient well-formedness focuses on models which assign scalar well-formedness values, but this is only one component of any such model. Since these models take linguistic representations as input, there must be a recognizer-parser able to accommodate an enormous range of linguistic structures; for instance, no score can be assigned to [bznk] unless it can be assigned a structural representation. However, speakers have difficulty perceiving and producing phonotactically ill-formed nonce words (see §1.2), suggesting that parsing of illicit representations is at best limited. Far less is necessary for reporting binary well-formedness judgements: the recognizer-parser can be allowed to crash on illicit structures, and speakers need only report whether parsing is successful or not. The fact that requests for repetition and clarification are ubiquitous in spontaneous speech illustrates that parsing does fail, and that speakers are aware of when this has occurred.

Many studies report strong correlations between well-formedness ratings and scores from gradient computational models (e.g., Albright 2009, Bailey & Hahn 2001, Hayes & Wilson 2008, Frisch *et al.* 2000, Vitevitch *et al.* 1997), but there are few attempts to compare categorical and gradient well-formedness models on an equal footing that would be needed to reject the simple binary model of well-formedness. A recent attempt to compare these models (Gorman in press a) finds that a primitive categorical baseline outperforms state-of-the-art gradient models.

3.4 Acquisition and the (in)dependence of phonotactic knowledge

Hayes (2004) argues that phonotactic learning occurs before lexical or phonological acquisition, and is therefore independent of other types of grammatical knowledge. This is inconsistent with the available experimental evidence available, however.

Typically-developing infants know their names and the names of their caretakers as early as 4 months of age (Bortfeld *et al.* 2005, Mandel *et al.* 1995, Tincoff & Jusczyk 1999). While infants are born able to distinguish between monosyllabic and bisyllabic words, infants are thought to recognize syllables "holistically" rather than as segment sequences (e.g., Bertoncini & Mehler 1981, Eimas 1999, Jusczyk & Derrah 1987). As early as 6 months of age, infants know the visual referents of familiar words presented auditorily (Bergelson & Swingley 2012). At 7.5 months, phonological representations are sufficiently detailed to allow infants to discriminate between words like *cup* and mispronunciations like **tup* (Jusczyk & Aslin 1995). By 8 months, infants are able to locate both familiar and novel words in continuous speech (Jusczyk & Hohne 1997, Seidl & Johnson 2006).

While very few studies have investigated young infants' knowledge of phonological alternations, this is the subject of a fascinating study by White *et al.* (2008). Simplifying somewhat, the experimenters expose 8.5-month-old infants to an artificial language in which fricative voicing is contrastive, but voiced and voiceless variants of plosives are in complementary distribution, appearing only after vowels (*na-bevi*) and after voiceless consonants (*rot-pevi*), respectively. After familiarization, infants prefer to listen to nonce words which preserve this complementary distribution of stops over words which do not (e.g., *na-poli*, *rot-boli*), suggesting

that the infants have extracted an allophonic generalization.

Crucially, all of this occurs *before* there is any evidence for phonotactic knowledge, for which the earliest evidence begins at approximately 9 months of age (e.g., Friederici & Wessels 1993, Jusczyk *et al.* 1993, 1994). While there are many gaps in current understanding (and keeping in mind the usual caveats about a strong interpretation of negative results), there is no reason to think that phonotactic knowledge is acquired before non-trivial amounts of lexical and phonological acquisition.

4 Conclusions

It has been argued that phonological processes wholly determine what speakers know about possible and impossible words in their language. Lexical tendencies are neither necessary nor sufficient. This is not to suggest that all phonotactic constraints inferred from the lexicon are illusory: for instance, Frisch & Zawaydeh (2001) present psycholinguistic support for co-occurrence restrictions in Arabic posited by Frisch *et al.* (2004 [1995]) on the basis of lexical data. As a general principle, however, it should be apparent that lexical statistics cannot be taken as unambiguous data for the theory of phonotactics.

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