

Lexicon against Naturalness: Unnatural Gradient Phonotactic Restrictions and Their Origins*

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Abstract

This paper presents two cases of lexically gradient phonotactic restrictions that operate against what would be phonetically natural: Tarma Quechua and Berawan. The paper shows that the unnatural trends in the lexicon are statistically significant, phonetically real, and show clear signs of productivity, with evidence from loanword phonology and from morphophonological alternations. Based on the two cases presented, we argue that gradient phonotactics *can* operate in the unnatural direction: in a context where one value of a feature (in our case, $[\pm\text{voice}]$) is phonetically dispreferred across languages, that marked feature value may actually be preferred by phonotactics (e.g., voiceless rather than voiced stops after a nasal or intervocalically). To our knowledge, this is the first report of a (truly) unnatural gradient phonotactic restriction on segmental structure. The unnatural gradient phonotactics in Tarma Quechua and Berawan bear theoretical implications: we demonstrate that Harmonic Grammar with CON restricted to natural constraints disallows phonotactic restrictions that favor the unnatural feature value in a given environment, contrary to what is attested in our data. Based on Author 1, the paper also proposes a new historical explanation for the development of these unnatural patterns. We argue that each of them is the result of a special sequence of three phonetically natural sound changes — a so-called “blurring chain”. This hypothesis explains several peculiar aspects of the data, derives the typology of natural/unnatural processes, and provides a new historical explanation for unnatural patterns in general.

Keywords: phonology, phonetic naturalness, gradient phenomena, sound change, phonotactics, Harmonic Grammar

1 Introduction

The question of how phonetic naturalness shapes language is relevant both for theories of synchronic grammar (Chomsky and Halle 1968:ch. 9, Stampe 1973, Hellberg 1978, Donegan and Stampe 1979, Anderson 1981, Westbury and Keating 1986, Archangeli and Pulleyblank 1994, Hayes 1999, Wilson 2006, Carpenter 2010, Becker et al. 2011, White 2013, Hayes and White 2013) and for theories of diachronic development (Ohala 1993, 2005, Hyman 2001, Myers 2002, Blevins 2004, 2008, Blust 2005, Kiparsky 2006, 2008). We present here a case of phonotactic restrictions on segmental features (specifically, the feature $[\pm\text{voice}]$) that are both lexically gradient (cf. Coetzee and Pater 2008) and phonetically unnatural (cf. Buckley 2000, Yu 2004, Coetzee and Pretorius 2010).

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For synchrony, these cases are interesting because they suggest that the power of phonetically arbitrary restrictions (one might even call them phonetically recalcitrant — see section 1.2) extends not only to categorical bans of certain sequences (Coetzee and Pretorius 2010), but even to manipulating the relative frequencies of certain sequences in the lexicon. For diachrony, on the other hand, we will use these cases to argue against the necessity of phonetically unnatural sound change, recently argued for by Blust (2005).

1.1 Background

In Optimality Theory (OT; Prince and Smolensky 1993/2004) and related theories (Harmonic Grammar: Legendre et al. 2006, Pater 2008, 2009; Maximum Entropy Grammar: Goldwater and Johnson 2003, Hayes and Wilson 2008), two questions have recently received increased attention in the literature: (i) how to represent gradient phonotactic restrictions in the grammar (Frisch et al. 2004, Anttila 2008, Coetzee and Pater 2008, Wilson and Obdeyn 2009), and (ii) whether and how to represent unnatural processes in the grammar (Hayes 1999, Buckley 2000, Hyman 2001, Blevins 2004, 2008, Yu 2004, Blust 2005, Wilson 2006, Hale and Reiss 2008, Samuels 2009, Carpenter 2010, Coetzee and Pretorius 2010, Becker et al. 2011, White 2013, Hayes and White 2013, i.a.). To our knowledge, however, there exists no systematic treatment of the intersection of these two topics: unnatural gradient phonotactics, i.e. phonotactic restrictions that, given a particular environment, target a single (segmental) feature and gradiently favor the value of this feature that is unnatural in that environment. This paper presents an initial investigation of such unnatural gradient phonotactic restrictions: we present two cases, Tarma Quechua and Berawan dialects, in which the lexicon trends in the unnatural direction, and we discuss some synchronic and diachronic implications that our analysis of these data bears.

Phonotactic restrictions and trends in the lexicon that are phonetically unmotivated are especially relevant for current phonological theory. Prince and Smolensky (1993/2004) set out to build a theory in which every process is motivated by a universal constraint inventory (CON); processes that have no clear motivation in the phonetics, or that run counter to universal phonetic tendencies, are naturally problematic to the initial goals of this theory (See also Chomsky and Halle 1968, De Lacy 2002 and many other for arguments in favor of universal phonological markedness). Phonetically unmotivated phonotactics are primarily discussed in light of the “surfeit of the stimulus” problem: there exist unmotivated statistically significant trends in the lexicon, but speakers often fail to generalize these unmotivated trends to nonce words (see, for instance, Becker et al. 2011, 2012, Hayes and White 2013). Hayes and White (2013), for example, identify ten potential “unnatural” phonotactic restrictions based on systematic gaps in the English lexicon and test in a behavioral experiment whether those restrictions are internalized by native speakers. Using Hayes and Wilson’s (2008) Phonotactic Learner to identify systematic gaps, they find that, for instance, the English lexicon features a restriction against / ζ / before a stressed vowel followed by an obstruent (*[+continuant, +voice, –anterior] [+stress] [–son] in constraint formalism; Hayes and White 2013). Most studies on this problem agree that speakers do not generalize unmotivated phonotactic restrictions to nonce words, with the suggestion that they might not be represented in grammar (Pycha et al. 2003, Becker et al. 2011, Becker et al. 2012, Hayes and White 2013, Gallagher 2016, Becker et al. 2017). Other studies (for instance, Hayes et al. 2009) suggest, instead, that unmotivated processes can actually be generalized to nonce words, but to a lesser extent than natural processes. Thus, the literature does not agree on the grammatical status of phonetically unmotivated phonotactic restrictions.

The other aspect of our data, beside its unnaturalness, that bears implications for phonological theory is the fact that restrictions are *gradient* rather than categorical. The necessity of encoding

gradient phonotactics in the grammar has recently been motivated on the basis of gradient lexicalized co-occurrence restrictions (Berkley 2000, Frisch et al. 2004, Anttila 2008, Coetzee and Pater 2008, Wilson and Obdeyn 2009, Zuraw 2010). Coetzee and Pater (2008), for example, discuss two cases of homorganic consonant co-occurrence restrictions: Arabic and Muna. In both cases, an Obligatory Contour Principle constraint (Leben 1973, McCarthy 1986) creates a pressure that is strong, but fails to reach categorical status because of lexical variation: homorganic consonants are dispreferred within the same root, but not completely ruled out. This dispreference, however, operates in the *natural* direction: a restriction against the co-occurrence of homorganic consonants is strongly motivated by both articulatory (Garrett and Johnson 2013) and perceptual factors (Gallagher 2010). The same is true for the other cases of gradient phonotactics cited above.

Before presenting our case for unnatural gradient phonotactics, we would first like to more precisely define phonetic unnaturalness. As we will argue in section 1.2 below, most cases of so-called “unnatural” phonotactic restrictions in the literature are in fact either phonetically motivated or phonetically moot (“unmotivated”), including the restrictions that were tested in the *surfeit of stimulus* experiments. To distinguish our cases from these, we will adopt a new subdivision of naturalness (Author 1) and focus on gradient processes that are not only phonetically unmotivated, but that operate against universal, phonetically motivated tendencies.

1.2 On naturalness

Traditionally, the naturalness of phonological processes has been conceptualized as a binary split between natural and unnatural processes (see, for instance, Kiparsky 2006, 2008). Natural processes are phonetically well-motivated and typologically frequent. Their high typological frequency is driven by the existence of phonetic precursors, which Yu (2013:398) defines as “systematic contextually-induced variations that parallel some cross-linguistically recurring sound patterns”. Unnatural processes, on the other hand, are typologically rare or non-existent and lack phonetic precursors.

Such a division is, however, insufficient, as it fails to identify an important distinguishing feature within the “unnatural” group itself. All processes in the “unnatural” group indeed lack phonetic motivation or phonetic precursors. However, a subset of these processes not only lacks phonetic motivation, but also operates against universal phonetic tendencies — that is, against phonetic precursors responsible for a large number of (natural) phonological processes across many languages. Author 1 proposes a new division of phonological processes with respect to naturalness which we follow in this paper:¹

- (1) *A new division of naturalness*²

	Phonetic tendencies are	
	enforced by	contradicted by
natural processes	✓	✗
unmotivated processes	✗	✗
unnatural processes	✗	✓

Consistent with the literature, natural processes are defined as having clear articulatory or perceptual motivations and being typologically prevalent. Unmotivated and unnatural processes

¹Similar, but slightly different distinctions have been proposed before, see Morley (2014). For Morley (2014), for example, “anti-natural” processes need to violate implicational universals and they are defined as “unattested patterns that do not conform with posited language universals”.

²In this paper, “process” is an umbrella term for synchronic alternations as well as phonotactic restrictions.

are similar in that they both lack articulatory/perceptual motivation, i.e., they have no phonetic precursors. However, in contrast to unnatural processes, unmotivated processes have no universal phonetic tendencies that militate against them — see the examples in (3), taken from Blevins (2008). On the other hand, (true) unnatural processes not only lack articulatory/perceptual motivation, but also operate against universal phonetic tendencies. In other words, if $A > B / X$ is a universal phonetic tendency, $B > A / X$ is an unnatural process.

To be precise, we will define a *universal phonetic tendency* as a unidirectional phonetic and phonological pressure that has a clear articulatory or perceptual motivation, and operates passively across different languages (Author 1).

(2) *Universal Phonetic Tendency* (UPT)

A unidirectional phonetic and phonological pressure that has a clear articulatory or perceptual motivation, is typologically common, and operates passively cross-linguistically.

For example, post-nasal voicing, intervocalic voicing, and word-final devoicing are universal phonetic tendencies: they have clear articulatory motivations, are amply attested cross-linguistically as typologically common phonological alternations, and operate passively even in languages in which such processes are not among the synchronic alternations (for discussion, see section 2).

As mentioned earlier, the literature on (un)naturalness has primarily focused on unmotivated processes. For example, most of the 26 listed examples in the survey of “unnatural” alternations in Blevins (2008) and the ten “unnatural” gradient phonotactic restrictions in Hayes and White (2013) are unmotivated rather than unnatural, according to the definition in (1). Consider, for example, the following processes from Blevins (2008) and Hayes and White (2013).

(3) *Some processes labeled as “unnatural” in Blevins (2008) and Hayes and White (2013)*

a. /p/ → [s] / __i

b. /i/ → [u] / d__

c. * $\begin{bmatrix} +COR \\ +cont \\ -strid \end{bmatrix} \begin{bmatrix} -stress \\ +round \end{bmatrix}$ (“No [θ, ð] before stressless rounded vowels”)

d. * $\begin{bmatrix} +cont \\ +voice \\ -ant \end{bmatrix} [+stress] [-son]$ (“No [ʒ] before stressed vowel + obstruent”)

All these processes lack phonetic motivation, but they do not operate against universal phonetic tendencies. In other words, it is not the case that [θ, ð] in the context before unstressed rounded vowels are universally preferred: there exists no cross-linguistic passive phonetic tendency that would prefer fricatives before unstressed rounded vowels.

Few truly unnatural active alternations are reported and there is debate as to whether unnatural processes are, in fact, possible as productive synchronic alternations. The most compelling case of an unnatural synchronic alternation is post-nasal devoicing (PND) in Tswana and Shekgalagari (Hyman 2001). PND qualifies as unnatural according to all criteria laid out in this section: it operates against the well-motivated, typologically common, and passive phonetic tendency of post-nasal voicing. Coetzee and Pretorius (2010) have shown that PND is phonetically real and fully productive: speakers generalize it to nonce words. On the other hand, one of the most convincing cases against unnatural alternations in synchronic grammars is that of final (de)voicing. While final devoicing is a highly common and phonetically motivated process (Steriade 1997, Iverson and Salmons 2011), its unnatural counterpart — final voicing — is not attested in any language as a synchronic process (Kiparsky 2006, 2008; for a possible exception, see Yu 2004 and de Lacy 2002).

This has led some scholars to conclude that final voicing is an impossible synchronic alternation (Kiparsky 2006, 2008). The question of whether fully productive synchronic alternations can be unnatural remains open.

1.3 Aims

To our knowledge, no systematic treatment of unnatural gradient phonotactic restrictions exists in the literature. The aim of this paper is to fill this gap. As already mentioned, most non-natural phonotactic restrictions discussed thus far (including the ten phonotactic constraints in Hayes and White 2013) are unmotivated rather than unnatural (according to our definition), and we have almost no information on whether gradient phonotactic restrictions can be unnatural. Some gradient restrictions that operate in the unnatural direction have recently been reported in light of the surfeit of the stimulus experiments mentioned in section 1.2, including (i) a higher rate of alternation in monosyllabic compared to polysyllabic words (Becker et al. 2012), and (ii) a stronger preference for antepenultimate stress in LLL words compared to HLL words (Garcia 2017). Strictly speaking, the first restriction does not contradict any universal phonetic tendency (perhaps just a universal phonological tendency). The second restriction targets non-segmental features and while the restriction is significant, it is also very subtle in magnitude (see Garcia 2017). This paper presents a novel analysis of the lexicon of two languages, the Tarma dialect of Quechua (data from Adelaar 1977 and Puente Baldoceda 1977) and the Berawan dialects (data from Blust 2002, 2005, 2013, and Burkhardt 2014), both of which have highly unnatural trends in the lexicon that target a single segmental laryngeal feature [\pm voice] and have a considerably greater magnitude than any cases of unnatural gradient restriction reported thus far. We will show that these trends run counter to specific universal phonetic tendencies, and we will argue that the trends are statistically significant, phonetically real, and morphophonologically productive. Based on these findings, we interpret unnatural trends as a gradient phonotactic restriction (in line with Coetzee and Pater 2008 and others).

The two case studies presented in this paper raise a theoretical question for the theory of Markedness (see, e.g., de Lacy 2002, 2004, 2006, de Lacy and Kingston 2013) in weighted-constraint theories like Harmonic Grammar (HG, Legendre et al. 2006, Coetzee and Pater 2008, 2011, Pater 2008, 2009, Albright 2009, Potts et al. 2010). While HG is able to derive gradient phonotactics (see, e.g., Coetzee and Pater 2008), we show that, without unnatural Markedness constraints, HG in its current form is unable to derive systems in which, given a context, the unnatural element in that context is more frequent than the natural element. Since the cases presented here are of this exact nature, this opens up the possibility that Markedness constraints might, after all, be able to counter universal phonetic tendencies (cf. Hayes and White 2013 and other work in that direction). Section 6.1 of this paper discusses this implication in more detail, and calls for future experimental work that should determine whether these particular unnatural gradient phenomena are extendable to nonce words, i.e. fully, not only morphophonologically, productive.

In addition, our two case studies have implications for diachronic analysis. The question of naturalness has also received increased attention in the diachronic literature; it is debated whether sound change *can* operate in unnatural direction (Garrett and Johnson 2013, Blust 2005), and the question of how to explain unnatural synchronic phenomena diachronically remains open. Several strategies for explaining the origins of unnatural processes have been invoked, from dissimilation to hypercorrection (Ohala 1981, 1993), and it has even been claimed that sound change can in fact operate in the unnatural direction (Blust 2005).

We argue that, even though the cases we present are unnatural synchronically, they can actually be accounted for with natural sound changes only, arguing against Blust's (2002, 2005) assertion

that sound change can be unnatural. We propose a novel explanation of the historical origins of the unnatural trends in the lexicon of Tarma Quechua and Berawan, as well as a new analysis of an alleged intervocalic devoicing sound change in Kiput (Blust 2002, 2005) which did not result in unnatural phonotactic restrictions. Building on previous work in Author (1), we argue that a combination of three natural sound changes (labeled the “blurring chain” in Author 1) operated in the development of all three languages.

The rest of this paper will be structured as follows. In section 2, we will give an overview of the universal phonetic tendencies relevant for our case studies, which all have to do with voicing. Next, section 3 will give an overview of the synchronic data for Tarma Quechua and Berawan and argue that these represent cases of gradient unnatural phonotactics. Following this, we will present data on the diachronic development of Tarma Quechua, Berawan, and Kiput in section 4, after which we will present our novel diachronic account of these scenarios in section 5. Section 6 will detail the synchronic and diachronic implications of our case studies, after which we will finish the paper with a conclusion in section 7.

2 Universal tendencies for voicing

All cases of unnatural phonotactics presented in this paper target a single phonological feature: $[\pm\text{voice}]$. Alternations and phonotactic restrictions targeting this feature are among the most well-studied phenomena in phonology and we have a substantial body of research on the typology as well as the phonetics of voicing cross-linguistically. The attention that voicing has received in the literature helps us determine in which environments the voice feature is universally dispreferred and vice versa, i.e. which processes targeting $[\pm\text{voice}]$ are “unnatural” according to the definition above.

Since unnatural processes are defined (cf. (1)) as running counter to a universal phonetic tendency, we will review the universal tendencies regarding voicing that are relevant to our case studies in section 3. The table in (4) summarizes these tendencies, and the paragraphs below summarize the evidence from the literature that these are indeed universal phonetic tendencies as defined in section 1.

(4) *Some universal phonetic tendencies for [+voice]*

	[+voice] preferred	[+voice] dispreferred
a. Intervocalic voicing	between two vowels	
b. Postnasal voicing	after [+nasal] consonant	
c. Voicing agreement	adjacent to [+voice] consonant	adjacent to [-voice] consonant

Intervocalic devoicing fulfills all criteria to qualify as an unnatural process under the definition in section 1: it operates against a universal phonetic tendency that is typologically very common, has clear phonetic motivation, and is active as a passive phonetic tendency. Intervocalic voicing is well attested: the survey in Gurevich (2004) and Kaplan (2010) shows that 26 of 153 (or 17%) languages surveyed feature intervocalic voicing as a synchronic alternation. Intervocalic voicing is also well attested as a sound change: the survey in Kümmel (2007) reports over 40 languages with intervocalic voicing as a sound change. In fact, voicing is the most common form of intervocalic stop lenition, followed by spirantization, approximantization, and others which are less common (Kaplan 2010).

Moreover, there exists a clear articulatory phonetic motivation for intervocalic voicing. The difference in subglottal and supraglottal pressure is greatest in intervocalic position and is consid-

erably smaller in initial or final position; because a pressure difference is crucial for voicing, voiced stops will be preferred in intervocalic position and dispreferred initially or finally (Westbury and Keating 1986: 153). Westbury and Keating (1986) argue that intervocalically, voiced stops are articulatorily easier to produce than their voiceless counterparts and that any neutralization in the opposite direction (from the expected) would result in “added articulatory cost”.

Kaplan (2010) also argues in favor of a perceptual motivation for intervocalic voicing. Invoking the P-map (Steriade 2001), she claims that intervocalic voicing is the most common type of lenition (more common than spirantization and approximantization) precisely because perceptual differences between voiced and voiceless stops intervocalically are the smallest (i.e. smaller than perceptual differences between intervocalic voiceless stops and voiceless fricatives). Speakers then choose the minimal perceptual difference to repair the phonotactic restriction against intervocalic voiceless stops. Finally, intervocalic devoicing is a passive phonetic tendency: stops feature more voicing into closure intervocalically compared to other positions (Docherty 1992, Davidson 2016 and literature therein).

Voicing in post-nasal position is another universal phonetic tendency that targets the feature $[\pm\text{voice}]$. Post-nasal voicing is a common productive phonological alternation and sound change (Kümmel 2007): as reported in Hayes and Stivers (2010), Locke’s (1983) study identifies 15 out of 197 (or 8%) languages surveyed with post-nasal voicing as a synchronic alternation. The articulatory explanation for post-nasal voicing is described in detail in Hayes and Stivers (2000) and Coetzee and Pretorius (2010) and builds on previous work by Rothenberg (1968), Kent and Moll (1969), Ohala (1983), Ohala and Ohala (1993), and others. Two basic factors are identified: in the transition from the nasal stop into the oral stop of nasal-plosive clusters, the velum has to rise from its lowest position to a complete closure. During this transition, air can still escape through the nasal cavity (“nasal leakage”), which makes it more difficult to achieve the increase in supraglottal pressure necessary to cease voicing (cf. Coetzee and Pretorius 2010). Secondly, as the velum rises, the volume of the oral cavity increases, which again promotes voicing (Hayes and Stivers 2000, Coetzee and Pretorius 2010). Post-nasal voicing is also well-motivated from a perceptual perspective: cues for voicelessness, such as the release burst of a stop, or cues for voicing, such as low frequency energy, are reduced in post-nasal position (Coetzee and Pretorius 2010:405). Finally, voicing is a passive phonetic tendency in post-nasal position, i.e. stops universally feature more voicing into closure post-nasally than in other positions (Hayes and Stivers 2000, cf. Davidson 2016).

The third tendency discussed in this paper, voicing in clusters of obstruents, is a universal phonetic tendency as well, fulfilling all three conditions mentioned above. Clusters that agree in voicing are typologically very common and voicing assimilation is one of the most common processes cross-linguistically (Myers 2010). Myers (2010) lists at least 28 such languages and the list is neither exhaustive nor does it result from a survey. The phonetic motivation is straightforward: laryngeal features “overlap and blend” in obstruent clusters which results in passive voicing of preceding voiceless stops due to laryngeal coarticulation (Myers 2010:164ff.). Perceptual factors have also been proposed to promote the agreement of laryngeal features (Myers 2010). Finally, agreement in laryngeal features fulfills the third condition of a universal phonetic tendency: voicing before another voiced stop is a passive phonetic tendency (Barry and Teifour 1999) and is attested in languages in which voicing assimilation is not a complete synchronic process. As Myers (2010) claims, “[a]coustic studies have shown that there is a longer voiced interval in an obstruent before a voiced consonant than before a voiceless consonant in English (Haggard 1978; Docherty 1992: 165; Stevens et al. 1992; Smith 1997; Jansen 2004), French (Snoeren et al. 2006), and Syrian Arabic (Barry and Teifour 1999)” (Myers 2010:164).

3 Unnatural trends in the lexicon

Our data from Tarma Quechua and Berawan violate all three phonetic universals laid out in (2). This section shows that the identified trends in the lexicons that operate against the three universal phonetic tendencies (UPTs) are statistically significant, phonetically real, and point to evidence in favor of the productivity of these processes.

3.1 Tarma Quechua

Tarma Quechua is a dialect of Quechua (Quechua I) spoken in Tarma district in the Junín province of Peru. The number of speakers is difficult to establish as the dialect is rapidly being replaced by Spanish (Adelaar 1977). Adelaar (1977) and Puente Baldoceña (1977) report approximately 30,000-40,000 inhabitants of the Tarma district and additional 3,500 inhabitants of La Unión Leticia. However, the number of speakers of the dialect with the particular unnatural phonotactics that are of interest here is much smaller and difficult to estimate.

3.1.1 Stop voicing

The Quechua dialect continuum almost uniformly has only voiceless stops in native vocabulary (Adelaar and Muysken 2004). However, Adelaar (1977) and Puente Baldoceña (1977) report that some of these voiceless stops have become voiced in Tarma Quechua (henceforth: TQ), or more precisely, the Quechua dialects spoken in Tarma, Huaricolca, Palcamayo, and La Unión Leticia. Voiceless velar and labial stops (with the exclusion of alveolars) are reported to undergo voicing in intervocalic and post-consonantal positions, but not after a nasal consonant. Adelaar (1977) and Puente Baldoceña (1977) note that voicing does not apply categorically (and that it does not apply post-nasally), but no further analyses on the lexicon are performed. Below we present results of a statistical analysis of the TQ lexicon that reveals a highly unnatural trend. We show that, in addition to limitations on voicing after nasals, the relative rates of voicing in different environments, including intervocalic and post-consonantal positions, contradict the universal phonetic tendencies from section 2. This paper, to our knowledge, is the first report of this unnatural distribution in TQ.

For the purpose of the analysis, we collected all tokens of stops from the vocabulary list in Adelaar (1977). Because alveolars never undergo voicing, they were omitted from the analysis – only labials and velars were kept. In addition, word-final stops and the first members of consonant clusters always surface as voiceless, so they were also excluded from the analysis. A total of 1199 tokens were collected: 910 tokens were from the native TQ vocabulary, and 289 are labeled as loans from Spanish in Adelaar (1977). Each data point was annotated for presence or absence of voicing, place of articulation of the stop (labial or velar), and position in the word. Five positions were included in the analysis: word-initial, post-nasal, intervocalic, position after a sonorant, and position after an obstruent. The initial raw data analysis reveals a surprising trend: voicing surfaces almost never post-nasally (9.5%), in almost half of the lexicon intervocalically (42.5%), and almost always post-consonantly, including in positions after a voiceless obstruent (86.1%).³

³Unless noted otherwise, the following symbols are used in this paper: T – voiceless obstruent, D – voiced obstruent, N – nasal, R – non-nasal sonorant, V – vowel.

	#_	N_	V_V	R_	T_
voiced	7	7	99	72	68
voiceless	276	67	134	13	11
% voiced	2.5	9.5	42.5	84.7	86.1

Table 1: Voiced vs. voiceless labial and velar stops in Tarma Quechua native vocabulary across contexts

To test the statistical significance of this trend, we fit a logistic regression model to the data with the R statistical software (R Core Team) using the *glm()* function. The first model includes only native vocabulary. The dependent variable was binary: presence or absence of voicing; the independent variables were Place of articulation (treatment-coded with two levels, labial and velar, with labial as the reference level), and Position in the word (treatment-coded with five levels: initial, post-nasal, intervocalic, post-sonorant, and post-obstruent, with intervocalic as the reference level) with no interactions. The best fitting model was chosen with the step-wise backwards model selection technique: higher order interactions were removed step-wise from a full model. If the likelihood ratio tests (LRTs) determined an interaction or predictor does not improve fit significantly, they were removed until all predictors in the model significantly improved the fit.

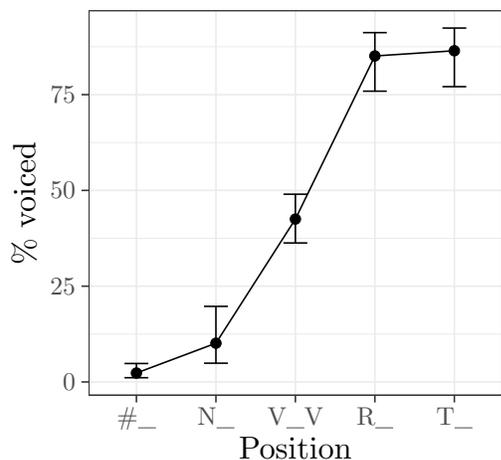


Figure 1: Percentage of voiced stops according to position

	Est.	SE	z value	Pr(> z)
(Intercept)	-0.045	0.172	-0.260	0.7952
V_V vs. R_	2.044	0.332	6.164	0.0000
V_V vs. T_	2.155	0.353	6.101	0.0000
V_V vs. N_	-1.884	0.421	-4.478	0.0000
V_V vs. #_	-3.437	0.407	-8.437	0.0000
velar vs. labial	-0.502	0.214	-2.344	0.0191

Table 2: Logistic regression model

As shown in this analysis, [+voice] in labial and velar stops is significantly less frequent word initially and post-nasally compared to in intervocalic position. [+voice] is significantly more frequent in post-sonorant and post-obstruent position compared to intervocalic position in TQ native vocabulary.

As argued in section 2, post-nasal and intervocalic position universally prefer voicing, while voiced stops after voiceless obstruents are universally dispreferred. The fact that TQ features less voicing post-nasally and intervocalically than after voiceless obstruents (the first members of a consonant cluster never underwent voicing)⁴ is thus highly unnatural. TQ voicing thus operates in a direction opposite to two universal phonetic tendencies: it operates more frequently where it is dispreferred (post-consonantly) and less frequently where it is preferred (post-nasally and intervocalically). These findings are summarized in the table in (5).

⁴The analysis shows post-nasal < intervocalic and intervocalic < post-obstruent, from which post-nasal < post-obstruent can be derived by transitivity.

(5) *Unnatural distribution of [+voice]*

Universal tendencies for [+voice]	Observed significant trends in TQ
T__ < V__V	V__V < T__
T__ < N__	N__ < V__V < T__

These trends are significant even if we include loanwords in the analysis. Data with loanwords was fit to a model that initially had two independent variables: Position (treatment-coded with same levels as above) and Place of articulation (sum-coded with velar as the reference level). The significance of all main effects remains the same as in the native vocabulary, but now the Position \times Place interaction becomes significant.

Furthermore, if we add Loanword status as a predictor to our model, the fit improves significantly, but it is not clear whether loanword status as a predictor is justifiable in a cognitive model. It is likely that speakers are unaware of loanword status for many lexical items; if they are, the distribution of voice for loanwords ceases to be of interest (in this case speakers may use two different grammars that govern native and loanword phonologies; see, e.g., Itô and Mester 2002, 2003). The data were fit to a model with three independent variables: Position (coded as above), Place of articulation (coded as above), and Loanword status (sum-coded with native words as the reference level). All two-way interactions are significant and are included in the model. The significance of all main effects remains the same as before (at means of other predictors), except that the V__V vs. T__ ceases to be significant as a main effect. There is, however, a significant interaction Loanword \times Position — voicing is more frequent for native vocabulary items in post-obstruent position. Adding loanword status as a predictor also introduces a problem of data scarcity, since there are only seven loanwords with labials or velars in post-obstruent position. Other frequency differences remain significant: there is still more voicing intervocalically than post-nasally and, if we refit a model with post-nasal position as the reference level, voicing is more frequent in post-obstruent position than post-nasally ($\beta = 1.470$, $z = 0.692$, $p < 0.05$). Note again that V__V vs. T__ is also significant if loanword status is not included in the model as a predictor ($\beta = 1.860$, $z = 5.611$, $p < 0.0001$).

If we isolate loanwords from the native vocabulary, we do not observe any unnatural patterns, which is not surprising as the donor language, Spanish, does not feature any of the unnatural patterns in TQ. As will be shown below, however, the unnatural voicing pattern in TQ does apply to a subset of loanwords.

Another locus of gradient unnaturalness emerges in TQ if we look into the within-context distribution of voicing in the post-obstruent position: clusters that agree in voicing are gradiently dispreferred in TQ — clusters that disagree in voicing are significantly more frequent.

We saw that labial and velar stops surface as voiced in non-nasal post-consonantal position (Table 1). The following consonants are attested as triggering voicing: [t, tʃ, tʃs, k, s, ʃ, x, l, lʲ, r, j, w]. Note that the list includes voiceless fricatives, affricates and even voiceless stops. The following clusters of two stops are attested: [kb, tb, tg]. The table 3 below presents examples of clusters that disagree in voicing after each consonant (data from Adelaar 1977).

1 st member	2 nd member	
	Labial	Velar
t	lutbi	mutgi
tʃ	/	atʃga
tʃ̥	atʃba	matʃga
k	takba	/
s	tʃasbu	tʃasgi
ʃ	kaʃbi	ifgi
x	saxbi	manexax-gunas
l	tʃilbi	tʃilgi
r	karba	argu
j	ajba	ajga
w	kawbu	awgis

Table 3: Obstruent clusters in TQ (from Adelaar 1977)

Obstruent clusters that disagree in voicing are much more frequent than clusters that agree in voicing if the second consonant is either a labial or a velar. Table 4 shows the number of occurrences of obstruent clusters in which the second element is a labial or a velar. To test the statistical significance of this distribution, the data was fit to a logistic regression model with only voicing as the dependent variable (empty model). The main effect of Place of articulation was not significant. Second-element stops (labial and velar) are significantly more frequently voiced (as opposed to voiceless) in clusters with a voiceless first element in TQ native vocabulary ($\beta = 1.8$, $z = 5.6$, $p < 0.0001$). This significance remains if we add loanwords into the counts: the best fitting model includes the intercept and a main effect of loanword status (if it is justified cognitively). Voiced stops are more frequent in obstruent clusters compared to voiceless stops ($\beta = 1.4$, $z = 5.2$, $p < 0.0001$).⁵

	TT	TD	DT	DD
Count	11	68	0	0
Percent	13.9%	86.1%	0%	0%

Table 4: Voice feature in obstruent clusters

TQ thus features a statistically significant trend that restricts clusters agreeing in voicing in favor of disagreeing clusters. This trend is both gradient and unnatural.

The trend against agreeing obstruent clusters in TQ is unnatural in one additional respect. Table 4 shows a preference for TD clusters, compared to DT clusters — which goes against yet another phonetic tendency. Voicing is articulatorily easier to maintain in initial parts of closure than it is to onset voicing after a period of voiceless closure (Ohala and Riordan 1979, Ohala 1997). The reason for this articulatory dispreference is straightforward and has been identified as the Aerodynamic Voicing Constraint: airflow and a subglottal-supraglottal pressure difference, necessary for voicing, are sufficient during vowel articulation, but decrease into closure. The reason why voicing is articulatorily difficult to onset after a period of voiceless closure is that it is difficult to reinstantiate airflow and pressure difference — once the closure has caused them to decrease —

⁵This difference again ceases to be significant if we add loanword status as predictor (sum-coded), but that might be due to the very small number of loanwords with clusters. Also, see above for problems with adding loanword status as a predictor.

without releasing the stop closure completely. In addition, there is a typological tendency towards respecting the Syllable Contact Law (Vennemann 1988), which also prefers DT over TD clusters. Finally, decreasing phonation into closure is observed as a passive tendency in several languages (see, for instance, Möbius 2004, Davidson 2016). In other words, voicing has a universal tendency to decrease rather than increase during the closure. The restriction in TQ against DT (decreasing in voicing) clusters in favor of TD clusters (increasing in voicing) is thus unnatural: it operates against the universal phonetic tendency that decreases voicing into closure.

3.1.2 Phonetics

The phonological facts described above clearly indicate unnatural tendencies in the lexicon. However, it is not *a priori* obvious that the phonological transcription used for these facts was faithful to the acoustics. In the following, we present the results of a phonetic analysis of Tarma Quechua. No previous detailed phonetic analyses of the system of voicing in TQ exist: Adelaar (1977) and Puente Baldoceca (1977) are based on qualitative descriptions of recordings and are not supported by phonetic analyses. Our analysis confirms the phonetic reality of the TQ voice system as described above, making the case for true unnaturalness in the TQ data.

The analyzed recordings were obtained online⁶ in .wav format, sampled at 90 kHz⁷ with 16-bit quantization and analyzed with Willem Adelaar’s permission in the Praat software (Boersma and Weenink 2016). The recordings were made by Willem Adelaar in 1970 in Tarma, in the Junín province of Peru. The informant was a 35 year old male speaker of TQ. The recordings are noisy with considerable echo, but the analysis nevertheless reveals important aspects of the unnatural gradient phonotactics and of the phonetic system of TQ in general.

Figure 2 shows four waveforms and spectrograms of two TD clusters: [tb] and [kb]. All four spectrograms clearly show that the initial stop of the cluster is voiceless with almost no phonation into closure and that phonation does not start until the onset of the second stop’s closure. First-element stops in the clusters show some echo noise during closure, because the recordings were made in a non-isolated room, but the voicing bar of the second stop is clearly distinguishable from noise vibrations of the first stop in all four cases.

⁶Accessible online at: <https://corpus1.mpi.nl/ds/asv/?0&0%5C&openpath=node:1483874>

⁷The original sampling frequency is not known.

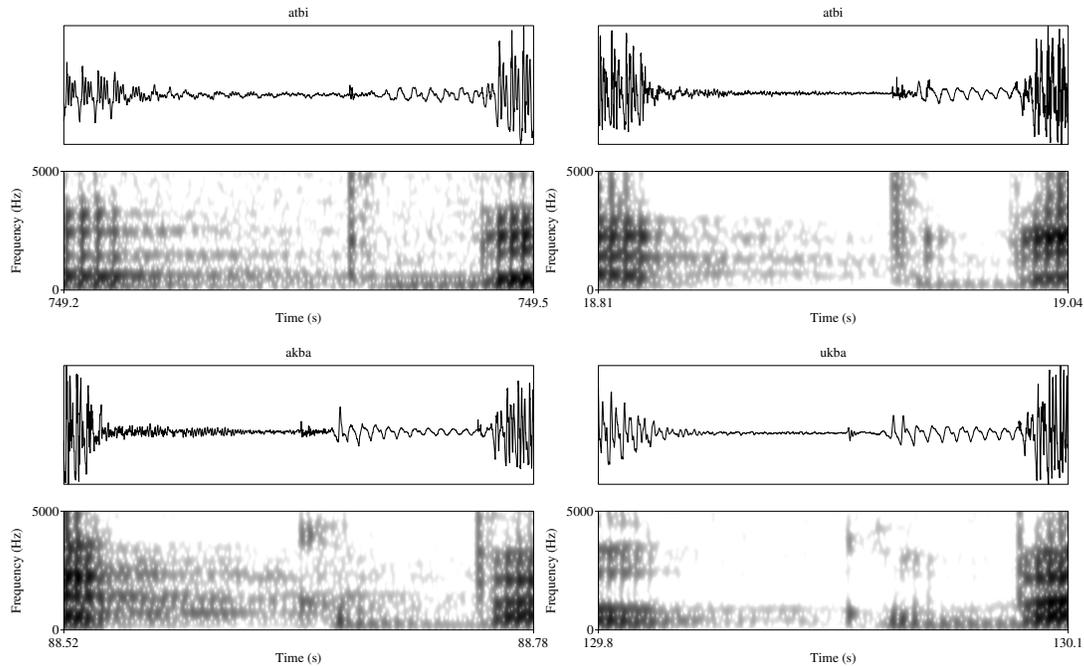


Figure 2: Waveforms and spectrograms of four TD clusters: [atbi], [atbi], [akba], and [ukba]

The same situation holds when the first element is an obstruent other than a stop, such as in the [sb] or [sg] sequences in Figure 3. The lack of any low frequency energy in the fricative portion of the cluster confirms that the first element, [s], is voiceless. Phonation starts at the onset of the stop.

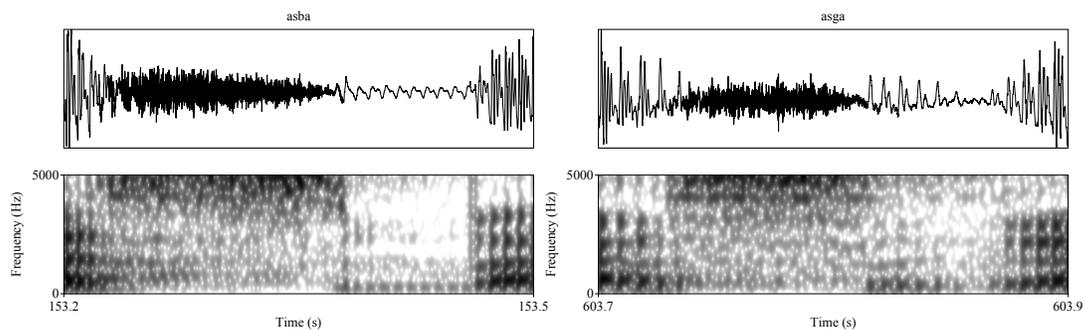


Figure 3: Waveforms and spectrograms of two TD clusters: [sba] and [sga]

The exact realization of voiced stops in clusters is not completely uniform and may vary. The exact distribution is difficult to establish with limited data, but a short transitional vocalic element is occasionally found between the voiceless and voiced obstruent, indicating a smaller degree of gestural overlap (Figure 4).⁸ Occasionally, the voiced element surfaces as a fricative. For details on fricative realization, see the discussion in 5.4.

⁸Occasionally, the second element is found to surface as voiceless or deleted.

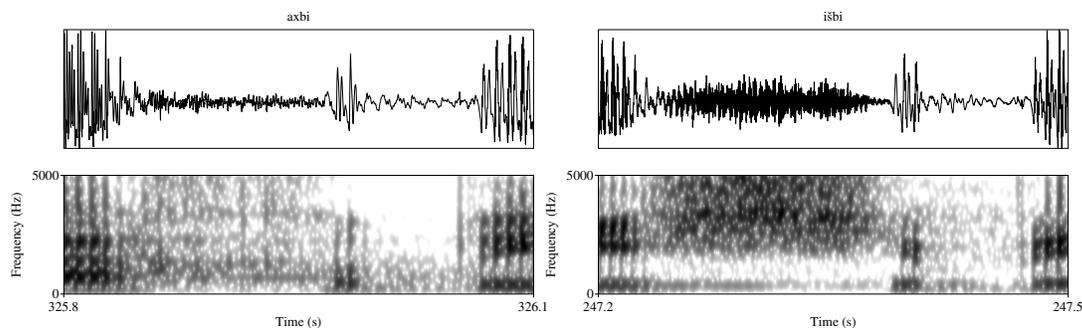


Figure 4: Waveforms and spectrograms of voiced labial stops in post-consonantal position with a short vocalic element between the voiceless and voiced element: [xb] (left) and [ʃb] (right)

After nasals, on the other hand, voiceless stops are the preferred variant, as detailed in Table 2. Figure 5 shows spectrograms with voiceless [p] and [k] after nasals. Also note that voiceless stops in TQ are unaspirated, which means that the phonotactic restriction in fact targets the feature [\pm voice] rather than the feature [\pm spread glottis].

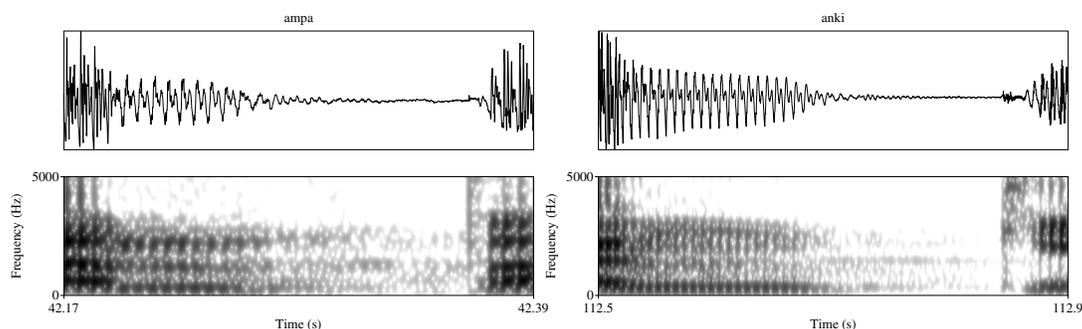


Figure 5: Waveforms and spectrograms of voiceless stops in post-nasal position: [mp] and [ŋk] (right)

3.1.3 Productivity

The unnaturalness of the gradient phonotactic restriction is phonetically confirmed by the recordings. Corroborating its status as a phonotactic restriction, there exists evidence that it is synchronically active in some morphophonological alternations. Creider (1968) and Adelaar (1977) identify four suffixes with an initial voiced labial stop that feature morphophonemic alternation:

- (6) *Alternating suffixes*
- a. -ba/-pa ‘genitive’
 - b. -bax/-pax ‘purposive’
 - c. -bita/-pita ‘procedentive’
 - d. -bis/-pis ‘even, too’

The allomorph with voiced initial stops is selected after vowels and non-nasal consonants, including voiceless obstruents; the allomorph with voiceless initial stop is selected after nasals (Creider 1968). The distribution is illustrated in (7).

- (7) a. *Intervocalic*
 wawxi-gi-**ba** wayi-n
 ‘the house of your brother’
- b. *Post-nasal*
 wayi-n-**pa** pasa-un
 ‘we’re going to walk by way of his house’
- c. *Post-obstruent*
 tamyā-ya-n nuqa-ntik-**baq**
 ‘it is raining now for us’ (Creider 1968:12-13)

This process is productive for a subset of suffixes. Other suffixes do not enter the alternation. For example, the highly frequent plural suffix /-guna/ and other suffixes /-bura/, /-gama/, and /-gasga/ have no voiceless allomorphs in post-nasal position (Adelaar 1977:59). The productivity of this morphophonemic alternation also differs across the dialects. Adelaar (1977:59) reports that voiceless allomorphs are required in Vicora Congas, whereas in Huanuquillo the rate of application varies, i.e. is gradient.

Nevertheless, even if this alternation is morphologically governed, the constraints that motivate the alternation (no voiced stops after a nasal, cf. Coetzee and Pretorius (2010), or no voiceless stop after a voiceless obstruent) are a part of the unnatural phonotactic restriction on the lexicon.

In addition, the behavior of loanwords provides further evidence for the productivity of unnatural gradient phonotactics. Most Spanish loanwords retain their original voicing. Sporadically, however, voicing or devoicing does occur (data from Adelaar 1977).

- (8) a. Sp. *cuculi* > kuguli: ‘white-winged dove’
 b. Sp. *cotpe* > kutbi ‘an animal from the mountains’
 c. Sp. *sauco* > sawgu ‘magic tree’
 d. Sp. *vaca* > wa:ga ‘cow’

In two loanwords, a Spanish voiced intervocalic stop devoices to a TQ voiceless stop (data from Adelaar 1977).

- (9) a. Sp. *taruga* > taruka ‘deer’
 b. Sp. *dios se lo pague* > jusulpa:ki ‘thank you’

The two loanwords with devoicing of intervocalic stop are especially relevant for the discussion on the productivity of TQ unnatural gradient phonotactic restriction. Devoicing in TQ [taruka] from Sp. *taruga* cannot be a result of an earlier borrowing, when TQ voicing supposedly did not operate yet: in TQ devoicing never occurs. The historical development of TQ involves only voicing of voiceless stops, not devoicing of voiced stops. Regardless of when Spanish *taruga* was borrowed, sound change could not have produced TQ [taruka]. This means that the gradient phonotactic restriction was likely productive and resulted from the law of frequency effect: because voiced stops surfaced in approximately half of the lexicon, nativization that matches native vocabulary frequencies is predicted to occasionally voice voiceless stops of the donor language and devoice voiced ones.⁹

The unnatural phonotactic restriction presented in this paragraph is reported not only for TQ, but also for one other Quechuan dialect. A very similar voicing process whereby Proto-Quechua *p and *k voice in the same positions as in TQ is reported in the dialect of Paccho (Adelaar and

⁹ Assuming of course that these loanwords were not borrowed to TQ via some other Quechuan dialect without the peculiar voicing process after the voicing was completed in TQ.

Muysken 2004, Adelaar, p.c.). The two dialects, Tarma and Paccho Quechua, are spoken in regions quite distant from each other and are potentially unrelated. Adelaar (p.c.) mentions that the two dialects might have been in contact historically, but the details are unclear. Because there are no descriptions or recordings of Paccho Quechua available, we leave this dialect out of our discussion.

3.2 Berawan dialects

The Berawan dialects are a group of closely related dialects that belong to the Berawan-Lower Baram group of North Sarawakan languages of the Malayo-Polynesian (Austronesian) language family (Blust 1992). Blust (1992) identifies four dialects of the Berawan dialect group: Long Terawan (LTn), Batu Belah (BB), Long Teru (LTu), and Long Jegan (LJ). They are spoken by approximately 3,600 speakers around Tutoh and Tinjar tributaries of the Baram river (Lewis et al. 2015, Blust 1992).

3.2.1 Restriction against intervocalic voiced stops

According to the description in Burkhardt (2014), the Berawan dialects feature two series of stops with respect to laryngeal features: voiced and voiceless, both series being unaspirated.¹⁰ Blust (2013) and Burkhardt (2014) report that an unnatural sound change, intervocalic devoicing (IVD), operates in Berawan: Pre-Berawan labial and velar stops devoice in Berawan and this devoicing is limited to intervocalic position. Alveolar stops do not devoice, but undergo lenition to [r] in intervocalic position (Burkhardt 2014:249). We will argue that these sound changes resulted in a synchronic pattern that disfavors intervocalic labial and velar voiced stops.

Neither Blust (2013) nor Burkhardt (2014) present any synchronic analysis of Berawan intervocalic devoicing. For the purpose of establishing the existence of an unnatural trend in the lexicon and its statistical significance, we analyzed all native vocabulary items from the vocabulary list in Burkhardt (2014). The list includes 425-466 vocabulary items, depending on the dialect. We counted occurrences of voiced and voiceless stops for all three places of articulation in all four dialects according to their position: initially and intervocalically. Clusters are disallowed in Berawan, which means that stops only surface initially, intervocalically, and word-finally. Word-final position is omitted from the count because stops are always voiceless word-finally in accordance with the natural process of final devoicing.¹¹ We included alveolar stops in the count because, due to intervocalic lenition, they also surface less frequently intervocalically. Counts are presented in Table 5.

The raw data analysis reveals that voiced stops are almost categorically prohibited from intervocalic position where their occurrence ranges from 0 to maximally 4. In initial position, on the other hand, voiced stops are allowed and surface with slightly lower, but similar frequencies as voiceless stops. Figure 6 summarizes the distribution.

¹⁰The analysis in Burkhardt (2014) is based on recordings made using a Sony Minidisc recorder and further analyzed with Toolbox software (Burkhardt 2014:36-8).

¹¹For the development of voiced stops word-finally, see (21) below.

Dialect	Place	Voiceless		Voiced		% Voiced	
		#_	V_V	#_	V_V	#_	V_V
Batu Belah	labial	52	10	40	2	43.5	16.7
	alveolar	56	32	22	4	28.2	11.1
	velar	43	54	13	0	23.2	0.0
Long Teru	labial	46	13	38	2	45.2	13.3
	alveolar	54	31	22	2	28.9	6.1
	velar	40	55	11	1	21.6	1.8
Long Jegan	labial	49	10	40	2	44.9	16.7
	alveolar	55	32	22	3	28.6	8.6
	velar	44	58	10	0	18.5	0.0
Long Terawan	labial	41	11	48	1	53.9	8.3
	alveolar	60	25	21	3	25.9	10.7
	velar	50	19	14	0	21.9	0.0

Table 5: Occurrences of stops in Berawan

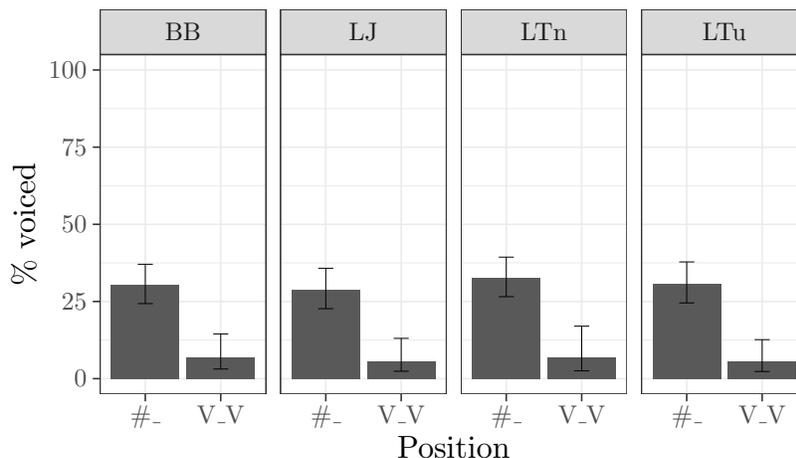


Figure 6: Percentage of voiced stops (across places of articulation) according to position — initial vs. intervocalic (from the logistic regression model in Table 6)

To test the statistical significance of the restriction against intervocalic voiced stops, the data for each dialect was fit to a logistic regression model. Presence or absence of the voice feature was the dependent variable and Position (treatment-coded with initial position as the reference) and Place of articulation (sum-coded with velar as the reference) were independent variables. Because of zeros in the count, the full model with all interactions was fit to a logistic regression model using bias-reduction (the model was fit using the *brglm()* function from *brglm* package; Kosmidis 2013). The interaction Place \times Position was not significant for any of the four dialects (tested with LRT), which is why the data was refit without this interaction to a logistic regression model without bias reduction (using *glm()*). The best-fitting model was chosen with LRT: for all four dialects it includes the main effects Position and Place.

In all four languages the voice feature in stops is significantly less frequent intervocalically compared to initial position. Table 6 includes estimates for the main effect Position for all four dialects.¹²

¹²In all four dialects the voice feature is also significantly more frequent in alveolars compared to the mean of all stops, but this is not of interest in this paper.

	Est.	z score	Pr(> z)
BB	-1.773	-3.906	0.0001
LTu	-2.028	-4.139	0.0000
LJ	-1.898	-3.860	0.0001
LTn	-1.893	-3.479	0.0005

Table 6: Estimates for the main effect Position (initial vs. intervocalic) from logistic regression models fit to Berawan data

Based on these models, we can conclude that the Berawan dialects feature a significant trend in the lexicon that restricts voiced stops intervocalically. The statistically significant restriction against intervocalic stops in Berawan is unnatural according to the definition in (1): it operates against the universal phonetic tendency of intervocalic voicing (see section 2).

The distribution of voicing in loanwords suggests that the gradient phonotactic restriction against intervocalic voiced stops was a part of productive alternations at least at some stage of development: devoicing in loanwords operates sporadically, i.e. gradiently. The collection of loanword vocabulary in Burkhardt (2014) includes cases in which devoicing applies regularly, e.g. Brunei Malay [pəsɪgupan] > Pre-Berawan *səgupan > BB [səkupen], as well as words in which no devoicing applies, e.g. Brunei Malay [sigup] > Pre-Berawan *sigup > BB [sigup].

This non-categorical devoicing in loanwords could also result from different lexical items being borrowed at different stages in the development, i.e. before or after the “intervocalic devoicing” sound change operated.¹³ One piece of evidence against this latter scenario is the fact that Batu Belah [səkupen] ‘pipe’ and [sigup] ‘tobacco’ both go back to the same Brunei Malay root, yet one undergoes devoicing and the other does not. It is difficult to argue that two lexical items of the same root were borrowed at different times, although it is of course not impossible. In a list of 15 loanwords in Burkhardt (2014), there are six cases in which a voiced velar or labial stop surfaces in intervocalic position in the donor language. In one case, devoicing occurs; in the remaining five cases the stops remain voiced.

The dispreference for intervocalic voicing remains significant even if we add loanwords to the count. In all four dialects, voicing is significantly less frequent intervocalically compared to initial position when loanwords are added to the count. Thus, we have demonstrated that the Berawan dialects exhibit a statistically significant trend in the lexicon — a dispreference for voiceless stops between vowels, which we interpret as a gradient phonotactic restriction as per the logic in Coetzee and Pater (2008). This gradient phonotactic restriction opposes a universal phonetic tendency, intervocalic voicing (see section 2), and is thus unnatural by our definition in section 1. This means that Berawan exhibits yet another case of gradient unnatural phonotactics.

4 Arguments for and against unnatural sound change

Thus far, we have shown that Tarma Quechua and Berawan phonotactic restrictions operate against three universal phonetic tendencies that target feature [±voice]: intervocalic devoicing, post-nasal devoicing, and voice assimilation in clusters. The simplest interpretation of these unnatural trends in the lexicon would be unnatural sound changes (Blust 2002, 2005). This section will first review evidence in favor of the hypothesis that a single unnatural sound change is responsible for each of the unnatural trends presented. Subsequently, we will point to intriguing aspects of historical development that are not accounted for under current diachronic explanations and that will be

¹³See section 5 for arguments against intervocalic devoicing being a single sound change.

crucial for our novel explanation of the historical data. Because diachronic treatments of Berawan and Kiput are more elaborate, we start with them.

4.1 Berawan

As already mentioned, Berawan dialects have been reported to undergo intervocalic devoicing (Blust 2013, Burkhardt 2014). Throughout this section, we will use the term IVD to denote a discrepancy between historical stages that may or may not correspond to a single sound change (in fact, we will argue in section 5 that it does not).

Berawan bilabial and velar stops **b* and **g* devoice intervocalically, but remain voiced word-initially. Bilabial stops undergo an additional change intervocalically: in addition to devoicing, they also change their place of articulation from bilabial to velar (**b > k / V__V*). Table 7 lists some cases of intervocalic devoicing reported in Burkhardt (2014) and Blust (2013: 667-8).¹⁴

Sound change	PMP/Pre-Berawan	Batu Belah
<i>*b > k / V__V</i>	<i>*abiəŋ</i>	akiŋ
	<i>*bibi</i>	biki
	<i>*bəlibiəw</i>	bəlikiew
	<i>*bibuj</i>	bikuj
	<i>*dibiən</i>	dikin
<i>*g > k / V__V</i>	<i>*bigiu</i>	bikiw
	<i>*gigiəq</i>	gikiʔ
	<i>*magi</i>	maki
	<i>*igiəŋ</i>	ikiŋ
	<i>*ugat</i>	ikit

Table 7: Examples of intervocalic devoicing in Berawan (data from Blust 2013 and Burkhardt 2014)

The list in Table 7 offers an illustration of intervocalic devoicing, but is far from exhaustive. In fact, IVD in Berawan is well-documented and almost exceptionless. A comprehensive study of Berawan dialects in Burkhardt (2014) includes between 425 and 466 vocabulary items for each of the four languages and Pre-Berawan reconstructions for each cognate (489 in total). Based on our counts, **b* or **g* appears intervocalically in 36 of these reconstructed words, and in all 36 cases the Berawan dialects show a voiceless stop, the regular reflex of **b* and **g* in intervocalic position.¹⁵

In contrast to intervocalic position, **b* and **g* remain unchanged in initial position. There are 46 reconstructed words with initial **b* in Pre-Berawan. In all but one word the initial **b* remains unchanged.¹⁶ A similar distribution holds for the velar voiced stop in initial position as well: **g* is reconstructed in twelve lexical items of Pre-Berawan and in all of them voicing is retained.¹⁷ Table 8 lists some examples of initial voiced stops in Pre-Berawan and Berawan.

¹⁴Proto-Malayo-Polynesian **r* and **g* developed to **g* in Pre-Berawan (Burkhardt 2014) and this change is applied to the reconstructed forms for the purpose of clarity.

¹⁵Long Terawan undergoes further changes that do not interact with our analysis (see Burkhardt 2014).

¹⁶In the one exception, devoicing occurs initially in all four dialects: **bəlippiəŋ > pəlipiŋ*. According to Burkhardt (2014:144), this development is sporadic in a word that already exhibits another sporadic development: degemination of -pp-. There is only one other example in which devoicing initially occurs only in Long Terawan: **buraq > [purəh]* (Burkhardt 2014).

¹⁷There is only one case of sporadic devoicing in Long Terawan.

PMP/Pre-Berawan	Batu Belah
*gəm	gəm
*gigun	gikuŋ
*gimot	gimok
*bitok	bitok
*buliən	bulin
*busak	busek

Table 8: Initial voiced stops (data from Blust 2013 and Burkhartd 2014)

A peculiar fact about the diachronic development of Berawan is that, while velar and bilabial stops undergo devoicing, alveolars undergo lenition in the same word-internal position. Pre-Berawan voiced alveolar stop *d remains a voiced stop initially, but develops to [r] word-internally. The summary of the developments is given in Table 9.

Pre-Berawan	Berawan	
	#_	V_V
*b	b	k
*d	d	r
*g	g	k

Table 9: Summary of developments in Berawan

In addition to the unexpected medial devoicing change, there is another quite natural type of devoicing operating in Berawan: devoicing of voiced geminates. Because geminates only appear intervocalically, this devoicing change is seemingly restricted to intervocalic position as well. Devoicing of geminates, however, is well-motivated as a context-free sound change. Since voicing is articulatorily difficult to maintain during the closure due to decreased airflow (Ohala 1983, 1997), and geminates have longer closures, voiceless geminates are universally preferred over voiced ones. Berawan geminates arose after schwa, from consonant clusters, and after “h-accretion”: addition of [h] at the end of words which caused shortening of vowels and consequently lengthening of consonants (Burkhartd 2014:260, 282-286). Unlike simple alveolar stops, geminate alveolar stops did undergo devoicing (7-c). Some examples of the development of geminates are given in (10).

- (10) *Origins of geminates in Berawan*
- a. *bunbun > *bubbun > buppuŋ
 - b. *tagraŋ > *taggaŋ > takkiŋ
 - c. *m-iddəm > mittäm

Geminate devoicing, too, contributes to the restriction against intervocalic voiced obstruents, precisely because geminates surface only intervocalically. However, because geminate devoicing is not unnatural and because voiceless geminates are preferred to voiced ones in all positions, we do not consider geminate devoicing to be a case for or against unnatural sound change, and we will not discuss these cases any further.¹⁸

¹⁸Labial geminate stops arising after schwa and from consonant clusters do not undergo a change in place of articulation (unlike simple stops), e.g. *təbu > *təbbu > [təppu], *mə-bənnən > *mə-ppənnən > *ppənnən > [pənnən] (after the loss of *mə- and initial degemination) or *əbbis > *əppiŋ > [piŋ] (after the loss of initial schwa and initial degemination). Geminates arising via “h-accretion”, however, do undergo a change in place of articulation:

4.2 Kiput

In addition to Berawan, intervocalic devoicing as a sound change has been reported for another Austronesian language: Kiput (Blust 2005).¹⁹ There, however, the sound change does not result in a significant unnatural trend in the lexicon. The language nevertheless provides insights into the historical development of unnatural phonotactics and helps us better understand intervocalic devoicing in Berawan (see section 5.3.2 for how this evidence factors into our proposal).

Kiput is a Malayo-Polynesian and, more specifically, North Sarawakan, Berawan-Lower Baram language of the Austronesian family, spoken by approximately 450 speakers in northern Sarawak in Borneo, Malaysia (Blust 2002). It features several peculiar developments which have been extensively discussed in Blust (2002). The most unusual of these is intervocalic devoicing, detailed in Blust (2002, 2005, 2013).

Blust (2002) establishes that the Pre-Kiput voiced velar stop *g, palatal affricate * $\hat{t}j$ and labiodental fricative *v devoiced to Kiput [k], [c̥c̥], and [f], respectively in intervocalic position.²⁰ Word-initial obstruents remain voiced. Word-final stops devoice by final devoicing; clusters are not allowed. Obstruents do not appear in other positions (Blust 2002).

Table 10 provides examples of intervocalic devoicing in Kiput. For the voiced velar stop series, the list is exhaustive: of 307 items on the vocabulary list with reconstructions in Blust (2002), four lexical items have intervocalic [g] in Proto-North-Sarawakan (PNS). In three cases, devoicing occurs. The fourth case is an exception to this rule: PNS *tegeraŋ yields Kiput [təgəriə]. For the developments [$\hat{t}j$] > [c̥c̥] / V__V and [v] > [f] / V__V the table lists only a subset of all cases from the list. There are altogether 19 and 9 cases of devoicing of [$\hat{t}j$] and [v], respectively, in the same 307-word vocabulary list.

they develop to voiceless velar geminate stops. The relative chronology of gemination and devoicing is difficult to establish. We have two possible scenarios: either (i) gemination precedes devoicing (*tuba > *tuga > *tuggah > [tukkih], argued for in Burkhardt 2014), or (ii) devoicing precedes gemination (*tuba > *tuga > *tukah > [tukkih]). Because the exact development cannot be reconstructed or is at best based on relative chronology, we will not discuss the geminate cases any further.

¹⁹Recently, intervocalic devoicing has been reported as a synchronic alternation for Sula in Bloyd (2017). It is clear from the data that the intervocalic devoicing there cannot be result of a sound change: devoicing operates exclusively at morpheme boundaries, whereas elsewhere voiced stops remain voiced intervocalically (Bloyd 2015). The existence of intervocalic devoicing as a synchronic process there does not speak against our proposal. The alternations are nevertheless interesting from a synchronic perspective: it seems that there is indeed synchronic intervocalic devoicing in Sula. Because the data are sparse and the language is poorly described, we leave Sula out of our discussion. Further investigations into the prehistory of Sula and its synchronic alternations are a desideratum.

²⁰All three consonants that devoice have transparent origins in Proto-North-Sarawakan (PNS; the direct predecessor of Pre-Kiput). Pre-Kiput *g goes back to a PNS voiced velar stop *g, whereas Pre-Kiput * $\hat{t}j$ and *v have various different sources in PNS. Pre-Kiput * $\hat{t}j$ continues PNS * $\hat{t}j$ or goes back to a PNS glide *j that is both phonemic and also automatic in hiatus sequences with high front vowel and a following vowel. By the same token, *v goes back to *w which can be either phonemic, or automatic in hiatus between a high back vowel and any following vowel (Blust 2002).

Sound change	Pre-Kiput	Kiput
*g > k / V__V	*agem	akəm
	*pager	pakəl
	*tugal	tukin
* \widehat{jj} > $\widehat{c\epsilon}$ / V__V	*pu \widehat{jj} ut	pu $\widehat{c\epsilon}$ ut
	*ta \widehat{jj} em	ta $\widehat{c\epsilon}$ əm
	*kaju > ka \widehat{jj} u	ka $\widehat{c\epsilon}$ əw
	*lia > lija > li \widehat{jj} a	lə $\widehat{c\epsilon}$ iħ
*v > f / V__V	* \widehat{jj} awaj > * \widehat{jj} avaj	da \widehat{f} iəy
	*sawa > *sava	sa \widehat{f} əħ
	*dua > *duwa > *duva	du \widehat{f} iħ

Table 10: Examples of intervocalic devoicing from Kiput (data from Blust 2002 and 2005)

As mentioned above, the obstruents *g and * \widehat{jj} remain voiced word-initially. There are seven lexical items with Proto-North-Sarawakan initial [g] in the 307-word Kiput vocabulary list. [g] remains voiced in all but one lexical item: Kiput [ketaan] for PNS *guta-an ‘able to endure pain’ (Blust 2002: 411).

The palatal affricate likewise remains voiced word-initially, but also loses its frication and develops to a voiced stop [d]. This occurs in three of four cases, e.g. * \widehat{jj} awaj > [da \widehat{f} iəj]. In one word the affricate retains its frication: PNS * \widehat{jj} auq yields Kiput [j \widehat{jj} əu?].²¹

The voiced bilabial fricative [v] does not appear word-initially.

The data presented here (from Blust 2002) thus confirms Blust’s (2002) claim that devoicing occurs exclusively intervocalically. Devoicing targets only the velar stop, palatal affricate, and labiodental fricative: voiced labial and alveolar stops remain voiced in all positions. The developments are summarized in Table 11.

Pre-Kiput	Kiput	
	#__	V__V
*b	b	b
*d	d	d
*g	g	k
* \widehat{jj} , *j	d	$\widehat{c\epsilon}$
*v, *w	/	f

Table 11: Summary of developments in Kiput (data from Blust 2002 and 2005)

Devoicing sometimes also operates in loanwords. Blust (2002) provides a list of 130 loanwords, mostly from Malay. In three cases, a borrowed voiced velar stop devoices, while it remains voiced in the remaining four, e.g. [sigup] → [sikup] vs. [bagi] → [ba \widehat{g} i?]. The voiced palatal affricate devoices in three loanwords and remains voiced in six loanwords, e.g. [pi \widehat{jj} it] → [pi $\widehat{c\epsilon}$ it] vs. [ra \widehat{jj} in] → [ra \widehat{f} im].

To sum up, the data presented above suggests that unnatural intervocalic devoicing occurred as a sound change from Pre-Kiput to Kiput. Blust (2005: 243) goes a step further and claims that intervocalic devoicing had to occur as a single sound change because it targets only one feature and because there exists “no possibility of considering a concatenation of natural changes which cumulatively produced an unnatural result.” In section 5, we will challenge this latter assumption.

²¹Blust (2002) claims that in two cases initial [\widehat{jj}] remains an affricate. However, Kiput [j \widehat{jj} əj] goes back to PNS [a \widehat{jj} aj] in which [\widehat{jj}] appears intervocalically. [j \widehat{jj} əj] is therefore not a case of preservation of an initial affricate.

Diachronic intervocalic devoicing is likely to have created an unnatural phonotactic restriction against intervocalic voiced velar, labiodental, and palatal obstruents in favor of the unnatural element in this position: voiceless obstruents. The fact that devoicing has happened in some loanwords provides evidence for this. However, the restriction was probably only active for a limited period of time, after which novel vocabulary was introduced in the language via borrowings and the alleged intervocalic devoicing ceased to operate. The fact that devoicing has only applied to loanwords sporadically, i.e. gradiently, may be evidence the the unnatural phonotactic restriction was gradient, as it is in the case of Tarma Quechua and Berawan. However, an alternative explanation is that loanwords were introduced to the language at different stages in its development.

In synchronic Kiput there is no significant restriction against intervocalic voiced [g] any longer. We analyzed Blust’s (2003) 932-word vocabulary list, which altogether contains 10 words with intervocalic [g] and 63 words with intervocalic [k]. It is true that the voiced velar stop occurs much less often than its voiceless pair in intervocalic position. However, this is likely to be a consequence of the fact that voiced velar stops in Kiput are in general less frequent than their voiceless pairs. The vocabulary list in Blust (2003) includes 121 instances of word-initial [k], but only 21 instances of word-initial [g]. The number of occurrences of [k] and [g] are represented in Table 12. Statistical significance is calculated using Fisher’s Exact Test and Pearson’s Chi-squared Test. The ratio of voiced vs. voiceless stops is almost identical across the environments. The restriction against voiced intervocalic stops is not statistically significant in Kiput, with p -value equaling 1.0.

Place	Voiceless		Voiced		% Voiced	
	#_	V_V	#_	V_V	#_	V_V
velar	121	63	21	10	14.8	13.7

Table 12: Voiceless vs. voiced stops in Kiput word-initially and internally

In sum, an unnatural sound change IVD is reported to operate in Kiput and the data seemingly suggest that IVD indeed operated in its pre-history. While the Kiput data do not provide direct evidence for the existence of unnatural gradient phonotactics, they offer important insights for the diachronic treatment of unnatural phenomena, as will be discussed below.

4.3 Tarma Quechua

No explicit treatments of the pre-history of TQ stop voicing exist in the literature. We know, however, that Proto-Quechua and Pre-Tarma Quechua only had voiceless stops, or at least had no voicing contrast. Adelaar (1977) describes neighboring dialects as featuring only voiceless stops; our acoustic analysis of these dialects with no voiced stops suggests that voiceless stops are indeed realized as phonetically voiceless in all positions.²² Therefore, it seems that voiced stops in TQ had to result from a sound change: voicing of voiceless stops.

If we posit that a single sound change produced this unnatural phonotactic restriction, we would have to assume that the sound change operates in a highly unnatural direction. The sound change would voice Pre-TQ voiceless labial and velar stops *p and *k to [b] and [g] intervocalically and post-consonantly, but not post-nasally. Such a sound change would thus operate in precisely the exact opposite direction of the universal phonetic tendencies described in section 2. Voiceless alveolar

²²Acoustic analysis was made on recordings of dialects of Tarma Quechua with no voiced stops. Recordings by Willem Adelaar are noisy and there exists some dialectal mixing, which makes the analysis difficult. Nevertheless, spectrogram analysis shows that a substantial low energy “voicing bar” is lacking in voiceless stops across phonetic positions.

stop *t would, however, have to remain unchanged in all positions (Adelaar 1977). Initial stops of any place of articulation would likewise have to resist voicing. These hypothetical developments along with reconstructions are given in Table 13.

Context	Voicing	Labial		Velar	
		Pre-TQ	TQ	Pre-TQ	TQ
#__	✗	*pirwa	pirwa	*kawa	kawa
N__	✗	*wampu	wampu	*tʃinka	tʃinka
V__V	✓	*kupa	kuba	*tʃaki	tʃagi
R,T__	✓	*takpa	takba	*kutʃka	kutʃga

Table 13: Stop voicing in Tarma Quechua (data from Adelaar 1977)

The most intriguing aspect about this hypothetical sound change is that this unnatural voicing operates gradiently rather than categorically with different rates of application across different environments. If this is indeed a single sound change, it thus appears as if at some stage of development it operated as sound change in progress and did not operate categorically. At the same time, the fact that voicing would have to operate with greater frequency in post-obstruent position than post-nasally and intervocalically makes the hypothetical sound change even more unnatural.

For these two reasons — its highly unnatural direction and its apparent in-progress operation — voicing in Tarma Quechua appears to constitute one of the more compelling cases of seemingly “unnatural” sound changes in the literature.

5 The origins of unnatural phonotactics

In this section, we propose a new and unified treatment of historical developments leading to the cases of unnatural gradient phonotactics presented in section 3. We argue that what appears to be a clear case of a single sound change that operates in the unnatural direction is better explained as a combination of three natural sound changes (the so-called “blurring cycle”). This approach automatically derives several unusual aspects of the data including the unnatural rates of application of voicing in TQ and the intriguing change of place of articulation in Berawan.

5.1 Previous accounts

The most elaborate historical treatment of the alleged unnatural sound changes in section 4 is given in Blust’s (2005) analysis of Kiput and Berawan. The discussion of the historical development of the two languages in Blust (2005) is closely related to Blust’s hypothesis that unnatural sound changes *do* exist. He first specifically rejects the possibility that intervocalic devoicing could be anything but a single sound change: “intervocalic devoicing affected a single feature value. There is thus no possibility of considering a concatenation of natural changes which cumulatively produced an unnatural result” (Blust 2005:243). According to Blust, the Berawan data directly attest to the existence of unnatural sound changes precisely because the unnatural intervocalic devoicing had to operate as a single sound change.

The most common strategy for explaining unnatural sound changes thus far is invoking Ohala’s (1993) hypercorrection. Blust (2005) proposes that IVD in Berawan can be considered a dissimilation based on hypercorrection. Because the opposite process, intervocalic voicing, is common, “the listener assumes wrongly that an assimilation has taken place and mentally ‘undoes’ it”

(Blust 2005:243). Blust (2005) also acknowledges the problems that such an explanation brings. First, $[\pm\text{voice}]$ is, according to Ohala (1993), a feature less commonly prone to dissimilation (Blust 2005:244). Moreover, as Blust (2005) acknowledges, the dissimilation by hypercorrection hypothesis fails to explain why devoicing operates only on a subset of places of articulation (e.g. alveolars undergo lenition instead of voicing).²³ Finally, hypercorrection is not well-suited for explaining the different rates of voicing in Tarma Quechua. It is unclear why hypercorrection would operate more frequently post-nasally than intervocalically or why it would operate more frequently post-consonantly than intervocalically.²⁴

Blust's (2005) argument against the possibility that multiple sound changes operated in the pre-history is also problematic. The fact that the sound change targets only one feature value is not in itself evidence that excludes the possibility of multiple sound changes operating in combination. In fact, we present a body of evidence arguing to the opposite: that one single sound change could not have operated in the history of Berawan dialects (see Table 18).

5.2 A model for explaining unnatural phenomena

The new explanation proposed here builds on the model for explaining unnatural processes presented in Author 1. The model was developed on the basis of post-nasal devoicing, an unnatural process that is reported as a sound change in twelve languages (Author 1) and as a synchronic productive alternation in two (Hyman 2001, Coetzee and Pretorius 2010). Author 1 argues that all twelve cases show either direct or strong indirect evidence that a combination of three natural sound changes occurred, together resulting in synchronic unnatural post-nasal devoicing. Author 1 also contains a proof for the claim that at least three sound changes are necessary for an unnatural alternation to arise, which is termed the Minimal Sound Change Requirement (MSCR). The central part of the model is a schema for explaining the sound changes needed for an unnatural process to arise, labeled the "blurring process" (Author 1).

Just like for post-nasal devoicing, it appears on the surface (and it has been claimed in the literature for Berawan and Kiput, Blust 2005) that single instances of unnatural sound changes operate in the development of Kiput, Berawan and Tarma Quechua. The fact that the unnatural phenomena in these languages are gradient is another argument in favor of a single sound change hypothesis: gradience is the prominent property of sound changes in progress. Using the "blurring process" model, however, we will argue that the seemingly unnatural sound changes and the resulting phonotactic restrictions in Kiput, Berawan, and Tarma Quechua arise from a combination of three natural sound changes, and we will point to advantages that this explanation bears over the alternative single-sound-change approaches.

Let us assume that a single sound change is a change in one feature in a given environment and is always natural, i.e. operates in the direction of universal phonetic tendencies. Let us assume that $A > B / X$ is one such natural sound change. Its opposite process, $B > A / X$, is, by definition, unnatural, as it operates against a universal phonetic tendency. The question addressed in this section will be: how can an unnatural process/phonotactic restriction $B \rightarrow A / X$ arise?

²³Other proposals that invoke dissimilation as perceptual enhancement or that claim intervocalic devoicing is phonetically motivated are also discussed in Blust (2005). All proposals face similar problems: they fail to account for asymmetries in voicing across different places of articulation and fail to derive the peculiar voicing distribution in Tarma Quechua. Due to the problems that all current proposals of intervocalic devoicing face, Blust (2005) leaves open the question of how exactly the unnatural sound change arose.

²⁴One potential explanation for a lack of voicing post-nasally within the hypercorrection approach could come from contacts with varieties of Quechua with post-nasal voicing (Adelaar and Muysken 2004). However, it is not clear that this contact occurred and how this hypercorrection could have occurred. Additionally, this leaves the difference in voicing rates between post-consonantal and intervocalic positions unexplained.

As already mentioned, the model in Author 1 explains unnatural phenomena as a result of a combination of a minimum of three sound changes. A single sound change by definition cannot produce an unnatural process. Two sound changes in combination can produce unmotivated processes, but not unnatural ones (this process has been described as “telescoping”; Wang 1968). For unnatural processes to arise, at least three sound changes need to operate (MSCR; for argumentation, see Author 1).

The three sound changes needed for an unnatural process $B \rightarrow A / X$ to arise can be generalized (from Author 1):

- (11) *Blurring process*
- a. A set of segments enters complementary distribution
 - b. A sound change occurs that operates on the changed/unchanged subset of those segments
 - c. Another sound change occurs that blurs the original complementary distribution

Two scenarios (combinations of three sound changes) have been identified by Author 1 to produce the unnatural $B \rightarrow A / X$. They are termed the “blurring cycle” and the “blurring chain”, respectively, and schematized as (from Author 1):

- | | | |
|------|-----------------------|-----------------------|
| | <i>Blurring Cycle</i> | <i>Blurring Chain</i> |
| (12) | $B > C / -X$ | $B > C / X$ |
| | $B > A$ | $C > D$ |
| | $C > B$ | $D > A$ |

Post-nasal devoicing in the twelve reported cases results from a blurring cycle (Author 1). Voiced stops first undergo complementary distribution: they develop to voiced fricatives except post-nasally. Then, the second sound change occurs — unconditioned devoicing of voiced stops. Because at this point stops surface only post-nasally, the apparent result is post-nasal devoicing. Finally, the last sound change occurs that blurs the initial complementary distribution: voiced fricatives occlude to stops.

This development is confirmed by several direct and indirect pieces of evidence. One of the languages in which post-nasal devoicing operates as a sound change is Yaghnobi. Yaghnobi presents direct diachronic evidence in favor of the blurring cycle analysis as all stages of the development are historically attested (see Author 1, Xromov 1972, 1987). The development is summarized in Table 14 (Author 1). The sound changes of the blurring cycle operating from Avestan and Sogdian (ancestors) to Yaghnobi that result in apparent postnasal devoicing are all directly attested in historical records (from Author 1).

Blurring Cycle		Example		
$D > Z / [-nas]$	$d > \delta / [-nas]_{-}$	Avestan	band	dasa
$D > T$	$d > t$	Sogdian	βand	đasa
$Z > D$	$\delta > d$	Yaghnobi	vant	*đasa
		Yaghnobi	vant	das

Table 14: Development of coronals from Avestan to Yaghnobi (data from Novák 2010)

In the following section, we will argue that intervocalic devoicing in Kiput and Berawan as well as the peculiar voicing process in Tarma Quechua is the result of the other type of blurring process described in Author 1: the blurring chain. We argue that the application of the blurring chain

model in (11) and (12) to Berawan and TQ explains several unusual aspects of these languages that existing proposals (see section 5.1) cannot account for.

5.3 A new explanation

5.3.1 Berawan

Stage 1 in a blurring chain is the development of a complementary distribution (11-a). The material presented in section 3 provides several pieces of indirect evidence for the assumption that stops in the three languages entered complementary distribution at some stage of the development. Table 9 summarizes the development of Pre-Berawan voiced stops, repeated here.

Pre-Berawan	Berawan	
	#__	V__V
*b	b	k
*d	d	r
*g	g	k

Table 15: Summary of developments in Berawan

The intriguing aspect of the development of Berawan is that, while the labial and velar series undergo intervocalic devoicing (fortition or a decrease in sonority), the alveolar series of stops undergoes intervocalic lenition, i.e. an increase in sonority. This asymmetry is hard to explain under other accounts. Under the blurring chain approach, the asymmetry is actually expected. Lenition of alveolars in intervocalic position suggests an earlier stage with complementary distribution (11-a). Pre-Berawan *d develops to [r] intervocalically and remains a voiced stop [d] initially. It is likely that the increase in sonority intervocalically followed a gradual path via fricativization of [d]: *d > *ð > [r] (which is a common sound change, cf. Kümmel 2007:60, 79). In other words, we reconstruct that voiced alveolar stops underwent intervocalic lenition to [r], likely through an interstage with [ð], which means that at some point in the development [d] was in complementary distribution: the voiced stop surfaced as a fricative intervocalically.

Based on the development of the alveolars, we can reconstruct that such complementary distribution underlies the other two series of stops as well. Let us posit that Pre-Berawan first undergoes intervocalic lenition in all series of stops, not just in alveolars. Intervocalic fricativization of voiced stops is a common and phonetically motivated (Kirchner 2001, Kaplan 2010) — i.e. natural — sound change. As already mentioned, the alveolar series preserves this initial stage of complementary distribution in today’s system: intervocalically, *d surfaces as [r] < *ð and does not undergo devoicing, while initially it is preserved as a voiced stop. Stage 1 of the development is illustrated in Table 16.

Pre-Berawan	Berawan	
	#__	V__V
*b	b	β
*d	d	ð > r
*g	g	ɣ

Table 16: Stage 1 in the development of Berawan

We propose that at the stage of complementary distribution in Pre-Berawan, another sound change (the second in the blurring cycle) occurred that targeted the changed subset of segments (11-b): unconditioned devoicing of voiced fricatives. Voicing in fricatives is highly dispreferred and articulatorily difficult to maintain — requirements for voicing and for frication are diametrically opposed which is the source of articulatory dispreference: “one condition requires oral pressure to be as low as possible, the other to be as high as possible” (Ohala 2006:688; see also Ohala 1983, 1997, Smith 1997). Unconditioned devoicing of fricatives is thus a natural, motivated, and common sound change. Because voiced fricatives at this stage surface only intervocalically, the result is an apparent intervocalic devoicing. Note also that because *ð further develops to [r], it escapes fricative devoicing and the original complementary distribution in the alveolar series is still preserved. Stage 2 is illustrated in Table 17.

Pre-Berawan	Berawan	
	#__	V__V
*b	b	ɸ
*d	d	r
*g	g	x

Table 17: Stage 2 in the development of Berawan

The blurring chain hypothesis has several advantages. The labial series of stops in Berawan not only underwent devoicing, but also change of place of articulation. The first advantage of the blurring chain approach is that this change of place of articulation is easier to motivate than under other approaches. The sound change [ɸ] > [x] or [β] > [ɣ] (if it happened prior to devoicing) is much more common than [p] > [k] or [b] > [g]. In fact, the only two cases of change of place of articulation from labial to velar in the survey of consonantal sound changes in Kümmel (2007) involve precisely fricatives; none are reported to involve stops. This distribution might be the result of greater perceptual similarity between [ɸ] vs. [x] or [β] vs. [ɣ] than between [b] vs. [g], although extensive studies on the perceptual aspects of this change are lacking — many studies that test perceptual confusability involve differences between non-strident and strident fricatives (e.g., Miller and Nicely 1955, Alwan et al. 2011). There exists some evidence of a perceptual motivation for the [ɸ] > [x] change: Redford and Diehl’s (1999) data suggests that [f] vs. [θ] (another non-strident fricative) is perceptually more confusable compared to [p] vs. [t]. Regardless of how we motivate it, the change from labial to velar place of articulation is a much more common sound change when the target is a fricative than when the target is a stop and an explanation that invokes the first is more desirable than an explanation that invokes the latter.

The change in place of articulation that operated in Pre-Berawan reveals another crucial piece of evidence in favor of the blurring chain approach: if we assume that intervocalic devoicing operated as a single sound change, we cannot chronologically order the change in place of articulation with respect to intervocalic devoicing. Let us consider the option that intervocalic devoicing operated as a single sound change. There are two logical chronological orders of intervocalic devoicing and the change of place of articulation: either one precedes the other or vice versa.

Chronology 1		Chronology 2	
1. intervocalic devoicing	b > p	1. change of place	b > g
2. change of place	p > k	2. intervocalic devoicing	g > k

Table 18: Two possible relative chronologies under the assumption that IVD operates as one sound change

If devoicing happened first, we would expect original [p] from Pre-Berawan voiceless *p to change its place of articulation as well. This does not happen: Pre-Berawan *apuj yields [apoj] and not **aku] in all four dialects. If the change in place of articulation happened first, we would expect it to operate in word-initial position as well. This does not happen: Pre-Berawan *bibi yields [biki], not **giki. The only possibility to chronologically order the two sound changes and derive the Berawan data with a single-sound-change approach is to limit the already unusual sound change — change of place of articulation in stops (b > g) — to an even more unusual environment, intervocalic position. This would be highly unexpected: stops are perceptually better cued internally than initially where formant transitions into closure are lacking. In the survey of consonantal sound changes in Kümmel (2007) there are no cases reported of a change of [b] to [g] in intervocalic position.

In fact, precisely the change of place of articulation that targets only intervocalic [b] while initial [b] remains unchanged strongly suggests that the two were at some point distinct sounds and that the sound changes of intervocalic devoicing and change of place of articulation operated on one of the two sounds in complementary distribution.

Finally, the last sound change under the blurring chain approach (11-c) that operated in Pre-Berawan was occlusion of the velar voiceless fricative *x to [k]. Occlusion of fricatives is a natural and motivated sound change as well, although not as unidirectional as the other two in the blurring chain. Kümmel (2007) reports at least two cases of unconditioned sound change [x] > [k]. The sound change is also phonetically motivated: fricatives require more articulatory precision than stops (Ladefoged and Maddieson 1996: 137). The occlusion of fricatives can be motivated as reducing this articulatory precision, i.e. laxing of articulatory targets.

The sound change, *x > [k], blurs the original complementary distribution and the result is intervocalic devoicing, as it is attested in Berawan today. The blurring chain in Berawan that results in D > T / V__V is summarized in (13).

- (13) *Blurring Chain in Berawan*
 D > Z / V__V
 Z > S
 S > T

The reconstructed trajectory can be illustrated on a lexical item that includes both an initial and an intervocalic stop: Berawan [biku] ‘pig’ from Proto-Austronesian *babuj > *bibuj.

- (14) *babuj > *biβuj > *biφuj > *bixuj > [biku]

In sum, there exist several advantages of the blurring chain explanation in Berawan. First, lenition of the alveolar series of stops automatically follows from the new analysis: it reveals an earlier stage of complementary distribution. Likewise, the change in place of articulation becomes well-motivated and consequently, we solve the chronology problem outlined above in Table 18. Finally, all sound changes posited are natural and well-motivated.

5.3.2 Kiput

Let us now turn to Kiput, where we also find clear traces of a stage with complementary distribution (stage 1 of the blurring chain). We claim that Kiput intervocalic devoicing, too, results from a blurring chain.

Sounds targeted by devoicing in Kiput are summarized in Table 19.

Pre-Kiput	Kiput	
	#_	V_V
*g	g	k
* \widehat{jj} , *j	d	$\widehat{c\check{c}}$
*v, *w	/	f

Table 19: Devoiced sounds in Kiput (data from Blust 2002 and 2005)

Note that, while \widehat{jj} undergoes devoicing intervocalically, it also undergoes a change in initial position: the affricate \widehat{jj} loses its frication part and develops to [d]. In other words, \widehat{jj} in Kiput enters into complementary distribution. At stage 1, \widehat{jj} surfaces as [d] initially and remains \widehat{jj} intervocalically. Let us reconstruct that, like in Berawan, the velar stop enters a similar complementary distribution (11-a): it surfaces as voiced fricative intervocalically and remains a stop initially. The voiced fricative [v] surfaces only intervocalically. Stage 1 is summarized in Table 20.

Pre-Kiput	Kiput	
	#_	V_V
*g	g	$\underset{v}{j}$
* \widehat{jj} , *j	d	\widehat{jj}
*v, *w	/	v

Table 20: Stage 1 in the development of Kiput

At this point, we can posit that the second sound change of the blurring chain operated (11-b): an unconditioned devoicing of voiced fricatives and affricates (stage 2). Fricative and affricate devoicing is a well-motivated natural sound change (see 5.3.1 above). The voiced palatal affricate devoices to $\widehat{c\check{c}}$, while the voiced labiodental fricative *v devoices to [f] and the voiced velar stop *y devoices to *x. Stage 2 is summarized in Table 21.

Pre-Kiput	Kiput	
	#_	V_V
*g	g	x
* \widehat{jj} , *j	d	$\widehat{c\check{c}}$
*v, *w	/	f

Table 21: Stage 2 in the development of Kiput

That fricatives indeed devoice in Kiput is confirmed precisely by the attested development $\widehat{v} > [f]$. While *x further develops to [k] via occlusion (just like in Berawan, (11-c)), [f] is still preserved as a fricative and directly shows that devoicing of fricatives operated in Pre-Kiput. Because affricates and fricatives only surface intervocalically, the blurring chain results in an apparent intervocalic devoicing.

5.4 Tarma Quechua

In the following, we argue that unnatural voicing sound change and the resulting unnatural phonotactic restriction against post-nasal voiced stops and agreeing obstruent clusters in Tarma Quechua result from a blurring chain development as well. We argue that TQ voicing did not operate as

a single sound change, but that the development, like in the cases described above and in Author 1, proceeded through a combination of three sound changes. We argue that the blurring chain approach automatically explains several peculiarities in TQ development that other approaches are unable to derive.

Stage 1 in the development of blurring chain is complementary distribution (11-a). Based on phonetic facts (for details, see below), we argue that the first sound change in the development of the blurring chain in Tarma Quechua was fricativization of labial and velar voiceless stops [p] and [k] to *ɸ and *x. The alveolar series of stops fails to undergo fricativization, likely because fricativization would result in a dispreferred dental voiceless fricative [θ]. Similar systems in which fricativization targets only the labial and velar series of stops to the exclusion of alveolars are reported in Nepali and Taiwanese (Kaplan 2010).

We argue that the reconstructed Pre-Tarma-Quechua fricativization operates with different rates of application across different phonetic environments. Fricatives are universally dispreferred in post-nasal position. In fact, even in languages that feature sequences of a nasal and a fricative (NZ), the transition from N to Z in the “vast majority of cases” include a transitional oral closure (Steriade 1993:410). We therefore expect the rate of application of fricativization to be the lowest in post-nasal position. Intervocally, fricativization is expected to operate more frequently than post-nasally: intervocalic fricativization is a common natural and phonetically well motivated sound change (Kirchner 2001, Kaplan 2010). Finally, in post-consonantal position fricativization is motivated by stop cluster avoidance: clusters of two stops are universally dispreferred and fricativization is employed to avoid these clusters.

Fricativization thus creates the first condition for the blurring chain: complementary distribution (11-a) in which voiceless stops surface as voiceless fricatives intervocally and in clusters. The second sound change in the development of the TQ blurring chain targets the changed subset in the complementary distribution (11-b): we argue that non-sibilant voiceless fricatives undergo voicing in prevocalic position. Voiced fricatives are universally dispreferred (Ohala 1997, 2006), but in a vocalic environment fricative voicing is a common sound change. The voicing of fricatives in TQ is almost exactly parallel to a voicing process in two languages: Catalan and Avestan. In Catalan, voiceless fricatives in final position undergo voicing before a following vowel or a sonorant, even when the fricative is preceded by a voiceless stop: in *cops amagats*, for example, the realization of /-ps/ is [-bz] (Wheeler 2005, cited in Strycharczuk 2012). The difference between Catalan and TQ is that in the former, voicing is restricted to final position and the preceding stop undergoes voicing assimilation, while in TQ this does not happen. In Avestan, the parallel is even more striking. The Avestan dental fricative *θ develops to a voiced dental fricative ⟨δ⟩ [ð] after voiceless fricatives ⟨f⟩ [f] and ⟨x⟩ [x] in prevocalic and pre-sonorant position, e.g. ⟨uxδa-⟩ [uxða-] < *uxθa- < *ukt^ha- (Hoffman and Forssman 2004). There are numerous further cases of voicing of fricatives in a vocalic environment. Kümmel (2007) reports at least 13 cases where fricative voicing in a vocalic or [+voice] environment is a sound change that operated on more than one fricative in the language; there are 31 more cases in which one of the fricatives in the system is targeted. The sound change of fricative voicing in a vocalic environment is also a phonetically motivated sound change with similar phonetic motivations as the intervocalic voicing of stops (see discussion above and Westbury and Keating 1986, Wheeler 2005, Strycharczuk 2012, Strycharczuk and Simon 2013, Davidson 2016). Data in Möbius (2004) also suggest that fricative voicing is a phonetic tendency in the context between a voiceless and a voiced sound.

The unnatural distribution of voicing in TQ becomes phonetically motivated under the blurring chain explanation: voicing distribution in fact goes back to distribution of fricativization. As already mentioned, fricativization is expected exactly as attested: least frequently post-nasally, more frequently intervocally, and most frequently in clusters.

The last sound change that operated in the blurring chain of TQ was occlusion of voiced fricatives “back” to voiced stops (11-c), just like in the development of Berawan and Kiput. This natural sound change (see discussion in 5.3.1) blurs the original complementary distribution and the result is the peculiar voicing of Tarma Quechua. The development is summarized in (15).

- (15) *Blurring Chain in Tarma Quechua*
 T > S / [-nas,-#]__
 S > Z / __V
 Z > D

There exists strong indirect dialectal evidence and direct phonetic evidence in favor of the proposed blurring chain explanation.

Dialectal data show that fricativization of voiceless stops is a common process across Quechua. Fricativization is reported as being “prominent” in dialects near Cusco and in Bolivia (Adelaar and Muysken 2004:199). In Cusco Quechua, for example, voiceless stops fricativize in clusters (from Adelaar and Muysken 2004:199):

- (16) *Fricativization of voiceless stops in Cusco Quechua*
 a. *aptay > [hax^wtay]
 b. *upyay > [uxyay]

Fricativization of voiceless aspirated stops also occurs in Imbabura Quechua (Adelaar and Muysken 2004:199).

- (17) *Aspiration and fricativization in Imbabura Quechua*
 Proto-Quechua *paki > *p^haki > Imbabura Quechua [faki]
 Proto Quechua *qipa > *k^hipa > Imbabura Quechua [xipa]

Note the exact parallel between TQ and Imbabura Quechua with respect to place of articulation of fricativization: only the labial and velar series undergo aspiration and fricativization, while alveolars retain the stop manner of articulation.

The fact that in TQ it is the second element in clusters that fricativizes is also not unmotivated. Most frequently, first elements (i.e. coda stops) undergo fricativization, but cases in which the second element fricativizes are attested too, e.g. Nivx (Shiraishi 2006, Kingston 2008).

In fact, fricativization of the second element likely finds internal motivation: fricativization of the second element results from the fact that only labials and velars fricativize in TQ. The following clusters of two stops are attested: [kb, tb, tg] (going back to *kβ, *tβ, *tγ < *kφ, *tφ, and *tx). Note that in two of the three clusters, the first element is an alveolar stop that cannot undergo fricativization. To avoid clusters of two stops, either the labial or the velar stop had to undergo fricativization and they happen to surface in the second position. For the [kb]-cluster, it is possible that both elements underwent fricativization, but that only the second one underwent voicing because it surfaced in prevocalic position. Later, fricatives occluded to stops in Tarma Quechua and the result is the regular [kb] < *xβ.

Finally, there exists strong direct phonetic evidence within Tarma Quechua itself that the proposed blurring chain is the most likely trajectory of TQ development, i.e. that the development proceeded through an interstage with fricatives. Phonetic analyses of TQ show that voiced stops in fact occasionally still surface as voiced fricatives in apparent free variation. Figure 7 presents waveforms and spectrograms of phonemic voiced stops that surface as voiced fricatives. Spectrograms clearly show that the manner of articulation of sounds in question is frication. Formants are present

throughout the consonantal part, even in cases where formants do not result from echo noise in the room — after a voiceless stop. Moreover, fricatives feature a gradual increase in amplitude and lack burst, a characteristic of stop consonants; both of these features are confirmed in the spectrograms.

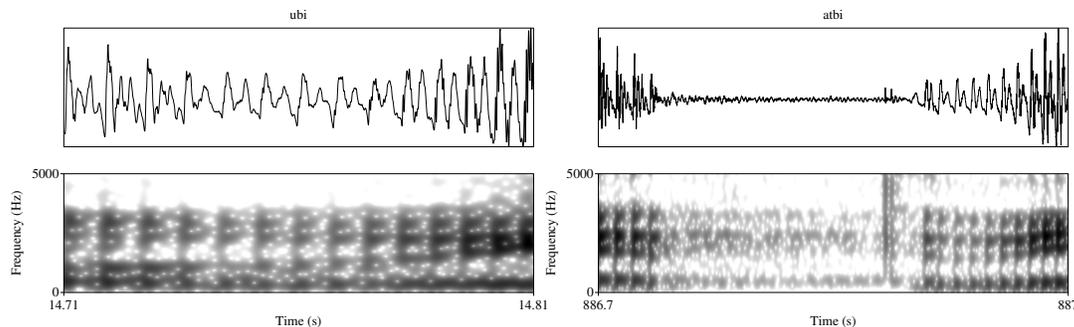


Figure 7: Waveforms and spectrograms of voiced stops that surface as voiced fricatives: intervocalically (left) and after a voiceless stop (right)

TQ phonetics thus preserves direct evidence that the unnatural voicing pattern developed through an interstage with fricatives and that the last sound change, occlusion of voiced fricatives to stops, does not operate categorically. In other words, the last sound change in the blurring chain seems to be in progress in the language recorded in Tarma in 1970.

There exists further phonetic evidence within TQ pointing to the validity of the blurring chain proposal. We saw that the last sound change reconstructed for TQ is the occlusion of voiced fricatives to voiced stops. That fricatives in TQ indeed undergo occlusion is suggested by the *voiceless* series of stops/fricatives. Puente Baldoceda (1977:9) reports that voiceless labial fricatives and labial stops are in free variation in Tarma Quechua. In other words, original voiceless fricatives are in the process of undergoing occlusion. This development is confirmed by cases such as Tarma Quechua [ɸlawta] ~ [plawta] (in free variation), borrowed from Spanish *flauta* with an original voiceless fricative. Exactly the same sound change in progress, occlusion of fricatives, is reconstructed by the blurring chain for the voiced series of fricatives.

In sum, the blurring chain explanation bears several advantages over the alternative strategies for explaining unnatural gradient phonotactics in TQ. Rates of voicing across different environments that are highly unnatural under other explanations now receive straightforward phonetic motivation: rates of voicing in fact go back to rates of fricativization. The asymmetries in voicing across places of articulation are also explained as fricativization targets only alveolars and velars. Evidence in favor of an interstage with fricatives is observed in synchronic acoustic analysis. Finally, all sound changes in the blurring chain explanation are phonetically motivated and typologically frequent.

6 Discussion

The analysis of unnatural trends in the lexicon bears theoretical implications in both synchrony and diachrony. We argue that unnatural gradient phonotactic restrictions *are* attested as significant trends in the lexicon. The existence of such trends have implications for both the derivation of unnatural processes in weighted constraint grammars as well as the derivation of gradient processes in general. We will discuss these implications in section 6.1.

In addition, we show in section 5 that — despite earlier assertions that unnatural devoicing and voicing are necessarily exceptions to the naturalness of sound changes — TQ, Berawan, and Kiput

are all compatible with and even better explained by a sequence of natural sound changes. This has important consequences for the theory of sound change, as detailed in section 6.2.

6.1 Implications for theories of synchronic phonology

Deriving non-categorical processes poses a challenge for OT with categorically ranked constraints (although see Anttila 1997, 2002, 2007, Nagy and Reynolds 1997, and Coetzee 2004, 2006 for models of variation with categorically (un)ranked constraints). On the other hand, the Harmonic Grammar (HG) family of grammar frameworks (Legendre et al. 2006, Coetzee and Pater 2008, 2011, Pater 2008, 2009, Albright 2009, Potts et al. 2010) has numerically weighted constraints and numerically defined well-formedness, which makes it well-suited for gradient processes (Pater 2009).²⁵ For our purposes, Maximum Entropy models (Goldwater and Johnson 2003, Hayes and Wilson 2008) are also a part of the HG family, since they also have weighted constraints and numerical well-formedness. We will focus here on this latter variant, since it defines a probability distribution over output candidates directly from the weights and violations of constraints, but the results presented here can be extended to other forms of HG.

The HG family has an advantage over categorical OT in that it can derive gradient processes (Pater 2009), which brings it closer to being able to account for unnatural gradient phonotactics. One problem, however, remains even under the HG approach: the derivation of unnatural processes. We will show that HG with restricted CON requires that, in any given context where CON defines a natural and an unnatural feature value, the natural value will have a probability that is at least as high as that of the unnatural value.

The classic version of OT (Prince and Smolensky 1993/2004) restricts its universal constraint inventory CON with the assumption that only a subset of possible constraints is universal and thus encodes typological asymmetries in the grammar. In HG, typological asymmetries that have to do with categorical patterns have also been tackled by restricting CON (see, e.g., Jesney 2016). There is, however, an additional aspect of the predictive power of HG under the restricted CON hypothesis that has gone largely unnoticed in the literature. If we restrict CON to only natural constraints, HG will predict that natural elements in a given environment will always be more frequent than unnatural ones (Author 1a).

We will illustrate this latter effect, which we call the “Natural Gradient Bias”, on the basis of final (de)voicing (see Blevins 2004, Kiparsky 2006). In our illustration, we will work with phonotactic probabilities of surface forms (see Hayes and Wilson 2008). However, since we want to incorporate the effect of Faithfulness, and Hayes and Wilson (2008) do not allow for Faithfulness constraints, we will use Jarosz’s (2006) method of marginalizing over inputs to arrive at phonotactic probabilities. Specifically, Goldwater and Johnson (2003) define probabilities of input-output mappings — $P(\text{output}|\text{input})$ —, which, given a prior probability over inputs and Bayes’ Rule, can be transformed into joint probabilities of outputs and inputs — $P(\text{output}, \text{input})$. We will assume that all inputs have a uniform prior probability, as Jarosz (2006) does for phonotactic learning.²⁶ Further following Jarosz’s (2006) approach, we can derive the phonotactic probability $P(\text{output})$ for every possible surface form by marginalizing over inputs.

²⁵Stochastic OT (Boersma 1997) and Jarosz’s (2015) framework also have numerically defined constraint rankings and define probability distributions over outputs for an input. The implications of our work for these frameworks should be similar. However, because these frameworks depend on variable categorical constraint ranking, the degree to which the results presented in this section carry over to these frameworks needs to be verified in future work.

²⁶This assumption can also be seen as a Bayesian interpretation of Richness of the Base (Smolensky 1996): we do not want to encode phonotactic information in the lexicon, so we should have an equal belief in the possibility of each underlying form. Note that the various inputs’ probability of occurrence in a language might not be uniform, but we abstract away from frequentist probabilities in this discussion.

In a categorical OT grammar with a restricted version of CON, the faithfulness constraints IDENT-IO(voi) and the natural, final devoicing-promoting markedness constraint *D# are admitted in the inventory, but crucially, unnatural *T# is excluded (cf. Kiparsky 2006). Under these assumptions, there cannot be a phonotactic restriction against voiceless obstruents word-finally: IDENT-IO(voi) \gg *D# implies faithful retention of word-final voiced obstruents, and *D# \gg IDENT-IO(voi) implies that all word-final obstruents are made voiceless. When we switch to HG, we have an infinite number of weightings for these two constraints, but Jarosz’s (2006) approach allows us to demonstrate that a gradient phonotactic restriction against voiceless obstruents word-finally is impossible with just these two constraints.

Given the assumption of uniform input probabilities, limiting our universe to $[\pm\text{voice}]$ at the end of a word means that the inputs /T#/ and /D#/ have 0.5 probability: $P(/T\#/) = P(/D\#/) = 0.5$. A restricted CON and weighted constraints combined yield the following implications: if the faithfulness constraint (\mathcal{F}) IDENT-IO(voi) has a positive infinite weight and the markedness constraint (\mathcal{M}) *D# has a finite weight, the phonotactic probabilities of [T#] and [D#] ($P([T\#])$ and $P([D\#])$) are both 0.5. If, however, the markedness constraint is weighted finitely lower than, or even higher than the faithfulness constraint, the phonotactic probability of [T#] will be greater than that of [D#] (Author 1a). Thus, a system that gradiently (or categorically) prefers [T#] over [D#] is impossible.

- (18) a. $w(\text{IDENT-IO}(\text{voi})) - w(*T\#) = \infty: P([T\#]) = P([D\#]) = 0.5$
 b. $w(\text{IDENT-IO}(\text{voi})) - w(*T\#) < \infty: P([T\#]) > P([D\#])$

The same reasoning can be used for any other natural-unnatural constraint pair, which illustrates the more general point that, if we allow only natural constraints into CON, we can only derive systems with gradient phonotactic restrictions in which the natural element in a given context is more frequent than the unnatural element. In other words, with restricted CON, no weighting exists that would yield a system in which the unnatural feature value has a greater posterior probability than the natural one in a given context.

- (19) a. $w(\mathcal{F}) - w(\mathcal{M}) = \infty: P(\text{nat}) = P(\text{unnat}) = 0.5$
 b. $w(\mathcal{F}) - w(\mathcal{M}) < \infty: P(\text{nat}) > P(\text{unnat})$

From (19), it follows that restricted CON allows either no phonotactic preference, or a phonotactic restriction against unnatural elements in favor of natural elements in a given environment: a Natural Gradience Bias.

(20) *Natural Gradience Bias (NGB)*

HG with restricted CON predicts that the probability of the natural feature value in a given environment is always equal or greater than the probability of the unnatural value in a given environment.

This generalization correctly predicts the major typological trend with regard to gradient phonotactic restrictions: all previously reported cases (both as trends in the lexicon, e.g., Berkley 2000, Pater and Coetzee 2008, and Anttila 2008, and as tacit phonotactic knowledge obtained from experiments, e.g. Albright 2009) indeed operate in the natural direction, where the natural element is preferred and more frequent than the unnatural one in a given environment. Moreover, our NGB assumption receives support from the modeling literature: Hayes (2016) has recently argued that in MaxEnt with restricted CON “[a] harmonically bounded candidate can never receive a higher

probability than the candidate that bounds it”.²⁷

However, the Tarma Quechua and Berawan systems of stop voicing presented in this paper suggest that HG with restricted CON undergenerates, since they require precisely the situation excluded by the Natural Gradient Bias: a higher frequency for the unnatural feature value in a certain context. Even with the flexibility of weighting allowed by HG, no weighting of natural Markedness constraints can generate cases like Tarma Quechua and Berawan. This, in turn, suggests that CON must contain some unnatural Markedness constraints.

However, to simply relax CON and allow all possible Markedness constraints is not a desirable solution either. Hayes and Wilson’s (2008) phonotactic learner is able to derive unnatural phonotactics because they do not limit CON to natural constraints — the learner is only provided with feature values and constraint templates. However, their model does not encode typological rarity of unnatural processes (although, see Pater 2012, Staubs 2014, and Author 1 on how typological rarity could be derived with unrestricted CON). Ideally, the grammar would be able to derive unnatural patterns and encode their rarity at the same time (for proposals, see Author 1b).

Before firm conclusions are drawn, however, the unnatural gradient phonotactic restrictions in the two languages would need to be confirmed experimentally.

Unnatural categorical *alternations* have already been confirmed as being productive elsewhere: Coetzee and Pretorius (2010) show that post-nasal devoicing in Tswana extends to nonce-words. Experimental nonce-word tests in Tarma Quechua and Berawan would reveal the degree of productivity and grammatical status of the two processes and therefore the ability of unnatural gradient phonotactic restrictions to be productive in general.

6.2 Diachronic implications

The new explanation also bears implications for the theory of sound change. First, we argued in section 5.3 that unnatural gradient phonotactics have the same origins as unnatural categorical phonological alternations, such as post-nasal devoicing (Author 1). The only difference between unnatural alternations and unnatural gradient phonotactic restrictions is that in the development of the first, all three sound changes of the blurring process have to operate categorically and have to be active sound changes. For the emergence of unnatural gradient phonotactics, sound changes in the blurring process are either not active/categorical anymore or are sound changes in progress. In fact, the blurring process shows that it is precisely a combination of natural sound changes that target surface allophones and do not operate categorically that results in unnatural gradient phonotactic restrictions.

The paper also bears implications for the discussion on the naturalness and restrictedness of sound change. The question of whether sound change can operate in the unnatural direction is open for debate, although most scholars assume unnatural sound changes to be impossible (see, e.g., Garrett and Johnson 2013). In fact, Garrett and Johnson (2013) list precisely intervocalic devoicing as an example of an impossible sound change. This view — that unnatural sound changes are not possible — has, however, often been challenged, most recently in Blust (2005). By showing that rare cases in which sound changes are reported to operate in the unnatural direction in fact result from a combination of natural sound changes, we can maintain the long-held position that restricts sound change to the phonetically natural direction.

The “blurring process” model argued for in Author 1 and here thus offers a new diachronic explanation of unnatural phenomena. Previously, the most commonly invoked strategies for explaining unnatural sound changes were dissimilation or Ohala’s (1993) hypercorrection scenario (Author 1).

²⁷Hayes (2016) calls this generalization “stochastic harmonic bounding”.

This paper argues that a “blurring process” model performs better than alternative approaches for the data discussed: several peculiarities that are not explained by hypercorrection follow automatically from the new proposal. The “blurring process” should thus serve as an additional diachronic strategy (together with hypercorrection) for explaining unnatural phenomena.

The new device for explaining unnatural phenomena (Author 1 and above) bears another advantage: it derives a typology of natural, unmotivated, and unnatural processes. Author (1) argues that unnatural alternations are typologically rare because at least three sound changes are required for an unnatural alternation to arise (MSCR, see section 5.2). The probability of three active sound changes occurring in combination in a given time frame is smaller than the probability of one or two active sound changes occurring in combination (Author 1). Based on this probabilistic interpretation, we can explain the difference in probability between natural, unmotivated, and unnatural alternations: natural processes are the most frequent because they arise through a single sound change, while unnatural processes are the least frequent because at least three sound changes are required (for more detailed argumentation, see Author 1).

A similar relationship holds for natural, unmotivated, and unnatural gradient phonotactic restrictions, although unnatural phonotactic restrictions do not follow the MSCR. As has been shown in this paper, the two gradient unnatural phonotactic restrictions discussed here arise through a combination of three sound changes and we can assume that the majority of unnatural phonotactic restrictions, like active alternations, arise from a combination of three sound changes as well. The model thus suggests a tendency for decreased frequencies of occurrence: most phonotactic restrictions are predicted to be natural, unmotivated ones are predicted to be less frequent, and unnatural restrictions the least frequent.

We also expect unnatural phonotactic restrictions to be more frequent compared to unnatural categorical alternations. The crucial difference between unnatural alternations and gradient phonotactic restrictions is that the first require all three sound changes in the blurring process to be active while for the latter the sound changes can be inactive or in the process of operating; the only condition for a blurring process to result in significant unnatural phonotactic restriction is that the three sound changes affect a sufficient amount of vocabulary. Precisely because active sound changes have more limited time frames, we expect unnatural phonotactics to be attested more frequently.²⁸

Finally, the blurring process has the potential to explain further unusual developments in the three languages discussed in section 5, especially in the Berawan dialects. Blust (2005) reports that another “bizarre” sound change operates in Berawan: voiced stops nasalize in word-final position.

- (21) *Final nasalization in Berawan*
D > N / __#

Final nasalization of voiced stops is a rare process, although not unnatural, but rather unmotivated because it does not operate against a universal phonetic tendency. Final nasalization is attested as a synchronic alternation in Noon (Merrill 2015), but it does not operate as a sound change there. Instead, a combination of sound changes leads to the rare final nasalization: voiced stops are first prenasalized and then develop to simple nasals word-finally and voiced stops word-medially (Merrill 2015). Final nasalization is never reported to operate as a sound change, except for in Berawan and some other Austronesian languages in Blust (2005, 2016). Because there are no traces of prenasalized stops that could lead to final nasalization in North Sarawakan, Blust

²⁸The generalization that unnatural gradient phonotactic restrictions are more frequent than unnatural alternations is, however, hard to test empirically as comprehensive treatments of *unnatural* (as opposed to unmotivated) alternations and restrictions are still lacking.

concludes that final nasalization had to operate as a single sound change.

Spontaneous nasalization is generally very rare typologically, but the one environment in which spontaneous nasalization is commonly attested and phonetically motivated is precisely the position before voiceless fricatives (Ohala and Ohala 1992, Ohala and Busà 1995). The blurring chain model proposed above reconstructs a stage in which original voiced stops surface as voiceless fricatives in word-final position — i.e. precisely the context where spontaneous nasalization is well-motivated. As already mentioned, final nasalization is reported in some other Austronesian languages (Blust 2016) and there too strong evidence for a stage with fricativization exists. The exact details of how the blurring chain can explain further “bizarre” sound changes and alternations, such as final nasalization, that other strategies fail to explain is, however, beyond the scope of this paper.

7 Conclusion

In this paper, we presented two cases of unnatural gradient phonotactic restrictions in the lexicon: Tarma Quechua stop voicing and intervocalic devoicing in Berawan dialects. We showed that the phonotactic restrictions operate in an unnatural direction (as defined in (1)): in the environments presented (post-nasal, post-voiceless-obstruent, and intervocalic), the articulatorily or perceptually preferred feature value is less frequent than the dispreferred feature value. We have shown that both restrictions are statistically significant and phonetically real. This appears to be the first report of unnatural gradient phonotactics that target segmental features in a segmental context. In sections 3.1.3 and 3.2.1, we provided evidence for the productivity of these phonotactic restrictions, which suggests that they are actually present in the grammar (see Coetzee and Pater 2008 and others for arguments that gradient phonotactic patterns must be present in the synchronic grammar).

We furthermore demonstrated that Harmonic Grammar (HG, Legendre et al. 2006, Coetzee and Pater 2008, Pater 2009) with CON restricted to phonetically natural constraints exhibits a Natural Gradient Bias (see (20) in section 6.1), according to which gradient phonotactics cannot be unnatural in the sense that the phonotactic restrictions discussed in section 3 are. Specifically, given a context that participates in a universal phonetic tendency, the feature that is universally dispreferred in that context (e.g., [-voice] after a nasal) cannot surface with greater frequency than the natural feature in that context (e.g., [+voice] after a nasal).

In addition, we have put forth a novel historical explanation for the development of unnatural phonotactics. Based on Author (1), we propose that a “blurring chain” of three natural sound changes operated in the pre-history of the discussed languages and that the three sound changes in combination result in the unnatural phonotactic restrictions observed. We have shown that the blurring chain can serve as a historical device for explaining unnatural processes, in addition to the most commonly invoked strategy thus far, hypercorrection. The paper also argues that a single sound change approach in fact cannot derive the data: we are unable to chronologically order sound changes if we assume that intervocalic devoicing in Berawan operates as a single sound change. By showing that rare reported cases of unnatural sound changes can actually be explained with a blurring chain, we can maintain the long-held position that sound change always follows phonetic naturalness. The blurring chain approach also better predicts typology: processes that require three sound changes are predicted to be rarer than processes requiring less sound changes.

In future work, we hope that our evidence for the gradient unnatural phonotactic patterns presented here will be corroborated with experimental data. Because of the relative inaccessibility of the Tarma and Berawan speech communities, obtaining such experimental data was outside the scope of this research. However, this type of evidence would greatly enhance the strength of our claim that CON should be able to contain at least the unnatural phonotactic constraints in our

data (cf. Coetzee and Pretorius 2010 for a constraint against [+voice] after nasals, which would be necessary for Tarma Quechua as well).

In addition, we hope to find new cases of gradient unnatural phonotactics, particularly ones that involve a feature other than [\pm voice]. Because unnatural gradient phonotactics as defined in (1) have not so far been the focus of phonological theory, we might expect more cases to be discovered in the future.

Finally, one issue that is not discussed in this current work is the calculation of historical probabilities that lead to unnatural gradient phonotactic restrictions. While the historical derivation of unnatural gradient phonotactic restriction resembles the historical derivation of unnatural alternations in many respects (see above and Author 1), there are also differences between the two, primarily in the form of temporal limitations. The framework outlined in Author (1) should provide a groundwork for calculating “historical probabilities” of unnatural phonotactic restrictions: probabilities crucially depend on the number of sound changes required for a process to arise (MSCR, see section 5.2) and their corresponding probabilities. While such work would give us more insight into the question of the typological rarity of (gradient) unnatural phonotactic restrictions, the evidence presented in this paper strongly suggests that such restrictions occur in at least some languages.

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