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Typological Asymmetries in Underapplication Opacity: A Gestural Account

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1. Introduction

A phonological process is characterized as a case of underapplication opacity when it fails to apply when it seems it should have based on its structural description (McCarthy, 1999; Baković, 2007, 2011). Two types of underapplication opacity have received particular attention in recent years: chain shifts and saltations.

A *chain shift* occurs when a phonological process applies only to non-derived forms. Abstractly, in a chain shift, underlying X changes into Y in some environment, but underlying Y changes into Z in that same environment. Such patterns are fairly widespread in phonology. One example comes from the consonant lenition of Gran Canarian Spanish. Word-initially, voiced and voiceless stops contrast; however, post-vocalically, voiceless stops surface as voiced (1a-c) while voiced stops surface as approximants (1d-f) (Broś, 2016; Broś & Lipowska, 2019; Broś et al., 2021).[1] In this case, two processes (voicing and approximantization) interact in an opaque manner: the approximantization that applies to underlyingly voiced stops underapplies to those voiced stops derived from voiceless stops.

(1) *Chain-shifting consonant lenition in Gran Canarian Spanish*

a)	[plaja]	'beach'	[la blaja]	'the beach'
b)	[taro]	'jar'	[kwatro daro]	'five jars'
c)	[kama]	'bed'	[la gama]	'the bed'
d)	[broŋka]	'fight'	[una βroŋka]	'a bed'
e)	[dama]	'lady'	[la ðama]	'the lady'
f)	[gama]	'range'	[la ɣama]	'the range'

On the other hand, a *saltation* occurs when a phonological process seemingly applies only to forms derived by some other phonological process. Abstractly, in a saltation, underlying X seemingly 'jumps over' more-similar Y to surface as less-similar Z in some environment, while underlying Y surfaces faithfully as itself in that environment. Like chain-shifting underapplication opacity, saltation is attested in consonant lenition. An example comes from Campidanian Sardinian, in which word-initial stop consonants contrast in voicing, but intervocalically, voiceless stops surface as voiced approximants (2a-c) and voiced stops surface faithfully (2d-f), (Bolognesi, 1998; Hayes & White, 2015; Katz & Pitzanti, 2019).[2] If we conceive of the lenition of voiceless stops as two distinct phonological processes, voicing and approximantization, the status of this pattern as a case of underapplication opacity is clear. Intervocalically, the voicing process applies to voiceless stops. However, approximantization appears to apply only to those voiced stops derived from voiceless stops, and not underlyingly voiced stops.

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[1] We follow Broś et al. (2021) in characterizing this as a process of approximantization rather than spirantization. As a result, the output segments are perhaps better represented in the IPA as [β̞ ð̞ ɣ̞]. We omit the diacritics elsewhere in the paper for ease of typesetting.

[2] Katz & Pitzanti (2019) report the results of a phonetic study showing that the lenition of underlyingly voiceless stops in Campidanian Sardinian produces voiced approximants without any frication noise. As in Gran Canarian Spanish, these sounds are probably best transcribed as [β̞ ð̞ ɣ̞]. Again, diacritics are omitted in the rest of the text.

(2) *Saltatory consonant lenition in Campidanian Sardinian*

a)	[piʃːi]	'fish'	[belːu βiʃːi]	'nice fish'
b)	[trintaduzu]	'thirty-two'	[sːu ðrintaduzu]	'the thirty-two'
c)	[kuatːru]	'four'	[de ɣuatru]	'of four'
d)	[bĩu]	'wine'	[sːu bĩu]	'the wine'
e)	[dominiɣu]	'Sunday'	[donːja dominiɣu]	'every Sunday'
f)	[gɔma]	'rubber'	[dɛ gɔma]	'of rubber'

Opaque phonological patterns are attested across a wide variety of phenomena. In alternations involving consonants, such as lenition, both chain shifts and saltations are attested, as exemplified above by Gran Canarian Spanish and Campidanian Sardinian. In related work (Smith & O'Hara, 2021), we show that among alternations involving vowels, such as height harmony, chain shifts are well attested but saltations are rare and possibly unattested. Smith & O'Hara (2021) further propose that the absence of saltatory vowel height harmonies can be explained within the framework of Gestural Phonology (Smith, 2018), which adopts the gestural representations of Articulatory Phonology (Browman & Goldstein, 1986, 1989). When represented in this framework, saltatory vowel harmony patterns are significantly more difficult to learn than chain-shifting patterns, because of the gestural parameters, in particular gestural *blending strength*, required to generate them. The question, then, is why cases of saltatory consonant lenition are attested while cases of saltatory vowel harmony are not.

In this paper, we propose that chain-shifting and saltatory patterns can be characterized as either one-dimensional or two-dimensional. One-dimensional patterns involve alternations along a single phonological dimension, such as consonant stricture or vowel height. Two-dimensional patterns, meanwhile, involve alternations along two distinct phonological dimensions. From this perspective, we examine the typology of opaque consonant lenition patterns and show that there is an asymmetry: both one- and two-dimensional chain shifts are attested, while only two-dimensional saltation is attested. We account for this asymmetry by adopting a gestural analysis of consonant lenition that allows us to represent one- and two-dimensional phonological processes, including consonant lenition, distinctly. We demonstrate this by examining Gran Canarian Spanish and Campidanian Sardinian, both of which exhibit two-dimensional consonant lenition processes involving consonant stricture and voicing. We compare such processes with one-dimensional consonant lenition in Finnish.

Crucial to our claim is that two-dimensional chain shifts and saltations are generated by very similar sets of gestural parameter specifications, predicting little difference in attestation between those processes. However, one-dimensional saltations require much more extreme gestural parameter specifications than one-dimensional chain shifts, providing an explanation for the lack of attestation of one-dimensional saltation. Furthermore, the attestation of saltatory consonantal processes and lack of attestation of saltatory vocalic processes can be attributed to consontantal processes' being more likely to be two-dimensional.

The paper is organized as follows. Section 2 provides an overview of gestural phonology and the mechanism of gestural blending. Section 3 presents analyses of two-dimensional cases of underapplication opacity, including the chain-shifting consonant lenition of Gran Canarian Spanish and the saltatory consonant lenition of Campidanian Sardinian. Section 4 presents an analysis of Finnish consonant gradation, an attested case of one-dimensional chain-shifting lenition and discusses why Gestural Phonology predicts a similar case of one-dimensional saltation is correctly predicted to be unattested. Section 5 examines the attested typology of opaque consonantal patterns and the gestural strengths necessary to generate such patterns.

2. Lenition via Gestural Blending

Following Smith (2020) and Smith & O'Hara (2021), we analyze cases of underapplication opacity as the result of gestural overlap and *blending*. In Articulatory Phonology (Browman & Goldstein, 1986, 1989), a phonological *gesture* is a dynamically-defined, task-based unit of subsegmental representation. Gestures are specified for a target constriction between an active articulator and a constriction location, as well as a blending *strength*. Gestural Phonology (Smith, 2018) adopts these gestures as the fundamental unit of representation in phonology. In this framework, gestures with conflicting target constrictions may overlap with each other in time. Following the Task Dynamic Model of speech production (Saltzman &

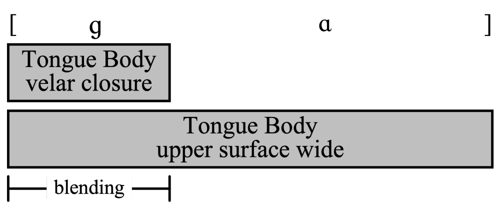
Munhall, 1989; Fowler & Saltzman, 1993), when such overlap occurs, the result is a blended production that averages the gestures' individual constriction targets, weighted by their blending strengths, denoted α, as in the equation in (3). When one gesture is much stronger than another, the blend resembles the stronger gesture; when they have similar strengths, the blend is intermediate between them.

(3)
$$\frac{Target_1 \times \alpha_1 + Target_2 \times \alpha_2}{\alpha_1 + \alpha_2}$$

Smith & O'Hara (2021) utilize this mechanism of gestural blending to account for cases of both chain-shifting and saltatory vowel height harmony processes. They also introduce the concept of *overpowering* relationships between gestures with conflicting target articulatory states. When a segment appears to fully assimilate to some other segment that overlaps it, or to fully resist that assimilation, the blended gestures of those segments must exist in an overpowering relationship. In such a relationship, one gesture has a blending strength that is an order of magnitude higher than that of the other gesture.

The only difference between the chain-shifting and saltatory opaque patterns lies in the set of blending strength ratios and overpowering relationships between vowels that generate each one. Here, we extend this account to cases of opaque consonant lenition. Instrumental study (Ohman, 1966; Browman & Goldstein, 2000) has shown that vowel articulations significantly overlap those of consonants that serve as their onsets. Represented gesturally, this is conceptualized as temporal overlap between consonant and vowel gestures in a gestural score, as in (4). Time is represented along the horizontal axis, with the length of each box representing the length of time for which each gesture is active.

(4) *Overlap between consonants and vowels in a gestural score*



We analyze consonant lenition as the result of blending between the gesture(s) of a consonant and those of the following vowel. Approximantization is the result of blending between a stop consonant's oral gesture (specified for a closed constriction) and a vowel's oral gesture (with an open constriction), producing a narrow constriction.[3] Voicing is the result of blending between a voiceless consonant's glottal gesture (specified for a spread glottis) and a vowel's glottal gesture (specified for a narrowed glottis), producing a blend that highly favors the glottal target of the vowel.

In prosodically strong positions where lenition does not occur (e.g., word-initially), we propose that the phonological grammar requires that the gestures of stop consonants surface with a relatively high blending strength, allowing them to resist lenition despite being overlapped by a following vowel. The framework of Gestural Phonology assumes a constraint-based grammar. However, for reasons of space, we do not spell out the precise constraint ranking/weighting that produces such a pattern.

Voicing and approximantization can both be analyzed as the results of gestural blending. However, it is crucial that each process is the result of blending gestures involving different active articulators: the tongue dorsum for approximantization, and the glottis for voicing. In the following section, we demonstrate how these two processes involved in consonant lenition can both be modeled in Gestural Phonology, characterizing the lenition patterns of Gran Canarian Spanish and Campidanian Sardinian as two-dimensional.

3. Two-Dimensional Lenition

Recall from section 1 that the cases of lenition in Gran Canarian Spanish and Campidanian Sardinian both involve voicing of underlyingly voiceless stops, and approximantization of some subset of the stops: the underlyingly voiced stops in the Gran Canarian Spanish chain shift and the underlyingly voiceless

[3] For the sake of clarity, we illustrate our approach only for dorsal consonants, whose oral gestures share a primary articulator with the vowels that overlap them.

ones in the Campidanian Sardinian saltation. In this section, we provide an analysis of both of these cases of lenition that rely on gestural blending between a consonant and a following vowel.

We analyze the voicing processes in both languages identically. We represent underlyingly voiceless consonants as including glottal spreading gestures and underlyingly voiced consonants and vowels as including glottal narrowing gestures. We assume here that glottal spreading gestures have a target constriction degree of 5mm, and glottal narrowing gestures have a constriction degree of 0mm, indicating light contact.[4] To generate the full voicing of a voiceless stop, that stop's glottal gesture must be *overpowered* by an overlapping vowel's glottal gesture. For instance, if the glottal gesture of the vowel has a strength of 24, and the glottal gesture of the voiceless stop has a strength of 1, the resulting constriction degree of the blended gestures is 0.2mm, as shown in (5). This is sufficiently close to the target constriction degree of 0mm specified for the glottal gestures of voiced segments such that this stop can be characterized as fully voiced.

(5) $$\frac{5mm \times 1 + 0mm \times 24}{1 + 24} = 0.2mm$$

Where the Gran Canarian Spanish chain shift and the Campidanian Sardinian saltation patterns differ is whether underlyingly voiceless or voiced stops approximantize. We illustrate the workings of our account with the blending calculations between a dorsal stop with a target constriction degree of -2mm (tightly closed) and the vowel /i/ with a target constriction degree of 4mm (high). We assume that approximants are produced by a constriction degree of 2mm (narrow).

Consider the Gran Canarian Spanish chain shift first. In this language, voiced stops approximantize in lenition contexts. Therefore, the dorsal gesture of a voiced stop must have a gestural strength half as strong as an overlapping vowel's dorsal gesture. The articulation produced by the blending of these two gestures has a constriction degree intermediate between the two individual gestures' individual target constriction degrees, as in (6).

(6) $$\frac{-2mm \times 1 + 4mm \times 2}{1 + 2} = 2mm$$

In order to generate the full resistance of voiceless stops to this approximantization process, the dorsal gesture of a voiceless stop must overpower that of an overlapping vowel. By setting the blending strength of the voiceless stop's oral gesture to 58 (and keeping the vowel's gestural strength at 2), the voiceless stop resists approximantization via blending and is produced as a stop, with a negative constriction degree indicating tight closure (7).

(7) $$\frac{-2mm \times 58 + 4mm \times 2}{58 + 2} = -1.8mm$$

In summary, we can model the Gran Canarian Spanish chain shift using the gestural strengths in (8). Notably, this analysis interprets the underapplication of the approximantization process as the result of differences in the specifications of voiceless and voiced stop consonants. More specifically, underlyingly voiceless stops' oral constriction gestures overpower those of vowels, resulting in resistance to approximantization, while underlyingly voiced stops' oral constriction gestures do not.

These same strength ratios and overpowering relationships can be used to account for the Campidanian Sardinian saltation (9), with one minor change: rather than approximantization (seemingly) underapplying to voiceless stops, it underapplies to voiced stops. To model this saltation pattern, the voiceless stops must be specified for the low gestural strength of 1, whereas the voiced stops must be specified for the high gestural strength of 58. Crucially, these two patterns are produced by symmetrical sets of specified blending strengths.

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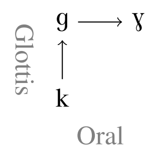
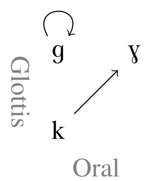
[4] The precise values used here are not crucial to the success of the analysis, nor is it crucial that we use values based on physical measurements as opposed to more abstract values.

(8) *Gestural Strengths for Two-Dimensional Chain-Shifting Lenition*



Oral Constriction		
k	V	g
58	2	1
Glottis		
V	k	
24	1	

(9) *Gestural Strengths for Two-Dimensional Saltatory Lenition*



Oral Constriction		
g	V	k
58	2	1
Glottis		
V	k	
24	1	

This result can be generalized across two-dimensional opaque phonological patterns that can be separated into overlap and blending of two different sets of gestures with target constrictions involving different active articulators. The chain shift X → Y → Z can be analyzed as the result of X comprising one weak and one strong gesture. Meanwhile, the saltation X → Z, Y → Y can be analyzed as the result of X comprising two weak gestures while Y comprises a weak and a strong gesture.

4. One-Dimensional Lenition

Not all cases of underapplication opacity in consonant lenition involve gestures specified for two different articulators, separating the two processes into two dimensions. Some instances are best understood as cases of one-dimensional underapplication opacity. One example of a one-dimensional chain shift comes from Finnish consonant gradation.

In Finnish and related languages, dating back to Proto-Finnic, consonants lenite when they appear in the onsets of closed syllables. In this gradation environment, geminate stops become singleton stops, and singleton stops undergo spirantization. In modern Finnish, singleton stops exhibit different patterns of gradation based on place of articulation, with /p t k/ surfacing as [v ɾ ∅]. In Old Finnish (Beesley & Karttunen, 2003), singleton stops /p t k/ surface as voiced fricatives [β ð ɣ] in the gradation environment (10). Due to its strong parallels with the cases of consonant lenition discussed in section 3, we will focus on the Old Finnish case here.

(10) *Chain-Shifting Finnish Consonant Gradation*

	Partitive		Genitive	
a)	[tipːaː]	'drop'	[tipan]	'drop'
b)	[rotːaː]	'rat'	[rotan]	'rat'
c)	[tukːaː]	'hair'	[tukan]	'hair'
d)	[ripaː]	'handle'	[riβan]	'handle'
e)	[sotaː]	'war'	[soðan]	'war'
f)	[likaː]	'dirt'	[liɣan]	'dirt'

Finnish consonant gradation can be analyzed as a one-dimensional chain shift in Gestural Phonology. We assume that geminate stops largely differ from singleton stops in having a more extreme negative oral constriction degree, producing an articulation in which the active articulator forms an oral constriction earlier and therefore maintains that constriction for a longer period of time. Thus, we analyze geminates in Old Finnish as being specified for an oral constriction degree of −4mm, singletons as specified for an oral constriction degree of −2mm, and voiced fricatives as specified for an an oral constriction degree of 2mm.[5] We also analyze consonant gradation as the result of a consonant's blending with the gesture of a following vowel with a constriction degree of 4mm. In prosodically stronger contexts where gradation is not observed, we assume that the phonological grammar requires these consonants to surface with a greater gestural strength that renders them immune to consonat gradation. Again, for reasons of space we do not elaborate on the workings of this grammar and how it produces this pattern.

The Finnish consonant gradation chain shift can be broken down into two parts: underlying singleton stops become fricatives, and underlying geminate stops become singleton stops.[6] In order to generate a pattern in which a singleton stop is produced as a fricative, the singleton must have half the gestural strength of the overlapping vowel. This is directly parallel to the blending that was proposed to occur between the oral gestures of vowels and voiced stops in Gran Canarian Spanish and of vowels and voiceless stops in Campidanian Sardinian, illustrated in (6) above. For a geminate stop to be produced as a singleton stop, the geminate must be specified for three times the blending strength of an overlapping vowel, as in (11).

(11) $$\frac{-4mm \times 6 + 4mm \times 2}{6+2} = -2mm$$

This lenition process, by which blending with a vowel widens the constriction degree of an overlapped consonant, applies to all stop consonants, and just affects geminates to a lesser degree than it does singletons. Because no stop fully resists this widening of constriction degree via blending with a vowel gesture, there is no need for any involved gestures to overpower one another and therefore no need for any of them to be specified for particularly high blending strengths, as indicated in (12).

(12) *Gestural Strengths for One-Dimensional Chain-Shift*

Chain-Shift

Oral Constriction	Oral Constriction		
kː ⟶ k ⟶ ɣ	kː	V	k
	6	2	1

However, a different picture emerges when attempting to generate an unattested one-dimensional saltation. We can imagine a hypothetical pattern similar to Old Finnish consonant gradation that instead is characterized by geminate stops surfacing as singleton fricatives or approximants while singleton stops surface faithfully. Such a pattern is derivable in Gestural Phonology, given the right set of blending strengths ratios and overpowering relations between consonants and vowels.

Assuming the same specified constriction degrees for geminate and singleton stops, the analysis of this hypothetical pattern proceeds as follows. For a geminate stop to surface as an approximant when blended with a vowel, it must have a strength one third that of the vowel that overlaps it, as shown in (13). Note that this is substantially weaker than the blending strength proposed for geminate stops in the attested Old Finnish pattern.

(13) $$\frac{-4mm \times 1 + 4mm \times 3}{1+3} = 2mm$$

In this hypothetical saltatory pattern, a singleton stop completely resists lenition when blended with a following vowel in order to surface faithfully. To do so, the oral constriction gesture of that stop must overpower that of the vowel that overlaps it, and therefore requires a substantially greater blending strength. If the singleton's oral gesture were specified for a strength of 87, and the vowel's oral gesture

[5] This constriction degree of 2mm parallels our analyses of Gran Canarian Spanish and Campidanian Sardinian. Again, the precise value is not crucial to the success of the analysis, and it would be straightforward to adjust the precise blending strength values we use here for Old Finnish to produce, for instance, a constriction degree of 1mm if evidence suggested that these Old Finnish consonants were better characterized as true fricatives.

[6] Singleton consonants also appear to become voiced in gradation contexts. We set that aside here in order to focus on the portion of this alternation that constitutes a chain shift.

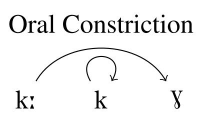
for a strength of 3, the result of blending would be -1.8mm, consistent with the production of a singleton stop (14).

(14)
$$\frac{-2mm \times 87 + 4mm \times 3}{87 + 3} = -1.8mm$$

Clearly, a one-dimensional saltation requires a very different set of gestural strength ratios than a one-dimensional chain shift. In a one-dimensional chain shifting consonant lenition process, all stops exhibit clear widening in oral constriction degree as a result of gestural blending with the gesture of an overlapping vowel; no consonant's gesture fully resists this lenition and therefore no consonant need overpower a vowel. In one-dimensional saltatory lenition, however, a singleton stop must fully resist lowering as a result of blending, thereby requiring an overpowering relationship with a vowel and a greater gestural strength (15).

(15) *Gestural Strengths for One-Dimensional Saltation*

Saltation



Oral Constriction		
k	V	kː
87	3	1

Smith & O'Hara (2021) present the results of learning simulations showing that opaque patterns only generated by more extreme gestural blending strengths are harder to learn than those generated by less extreme strengths. They identify *chains* of overpowering relationships as the primary drivers of extreme gestural strengths. A pattern in which no gesture need overpower any other gesture can be generated with a set of relatively low gestural strengths. On the other hand, a pattern in which one gesture must overpower another, which must in turn overpower a third gesture requires much higher gestural strengths to be generated accurately.

We can compare phonological patterns based on the most extreme gestural strength necessary to correctly generate them. One-dimensional chain-shifting consonant lenition requires no overpowering relationships, as all stops are subject to this constriction-widening process. As a result, all involved gestures may be specified for relatively low blending strengths. Two-dimensional chain shifting and saltatory lenition both require that the glottal gesture of a vowel overpowers the glottal gesture of a voiceless stop, and that the oral gesture of either a voiceless stop (in Gran Canarian Spanish) or a voiced stop (in Campidanian Sardinian) overpowers a vowel in order to resist approximantization. Even though two overpowering relationships are necessary to generate both of these two-dimensional patterns, they involve distinct articulators and therefore do not form a chain of overpowering relationships. As a result, extreme gestural strengths are not necessary to generate these patterns.

In the case of unattested one-dimensional saltatory consonant lenition, we also see that one overpowering relationship is necessary to generate the resistance of singleton stops to spirantization/approximantization. However, overpowering relationships are not the only factors in determining the gestural strengths necessary to model a pattern. Even if an overpowered gesture need not overpower another gesture to form a chain of overpowering relationships, generation of a pattern still might require a gesture to be specified for a higher blending strength, as the *distance* between the target constriction degrees of two blended gestures also impacts the blending strengths necessary for one to fully overpower the other. In our hypothetical one-dimensional saltation pattern, not only does a singleton stop need to overpower a vowel, but the vowel must in turn be strong enough to pull a geminate stop's constriction degree such that they blend to a constriction degree of 2mm, far from the geminate's specified extra-closed target constriction degree of -4mm. Because of this substantial spatial difference, a vowel must be stronger in our hypothetical one-dimensional saltation pattern than it was in either of our analyses of two-dimensional lenition patterns. As a result, a singleton must be even stronger in order to overpower it and resist lenition, and the pattern is characterized by overall more extreme blending strengths necessary to generate it.

5. Gestural Strength and Typology

We have shown that one-dimensional saltation requires more extreme gestural blending strengths than either two-dimensional chain shifts or saltations, which both require more extreme blending strengths than one-dimensional chain-shifts. The results of Smith & O'Hara (2021) suggest that this should be reflected in the typology of these patterns, as patterns that are only generated by more extreme gestural strengths are harder to learn.

We surveyed seventeen opaque consonantal processes in order to evaluate this typological claim. Thirteen of these processes were chain-shifting consonant processes reported by Neasom (2016) and sources within, while five were consonant processes classified as either saltatory or as phonologically derived environment effects reported by Hayes & White (2015); White (2013); Storme (2018). All five of these saltatory patterns could be separated into processes targeting two distinct articulatory dimensions, either voicing and oral constriction degree, voicing and nasality, or constriction degree and constriction location. Examples of each of these pattern types are provided in (5).

(16) *Two-Dimensional Saltations in Consonant Processes*

Voicing and constriction degree		
Campidanian Sardinian	/k/→[ɣ]	/g/→[g]
Manga Kanuri	/t/→[ð]	/d/→[d]
German	/g/→[x]	/k/→[k]
Voicing and nasality		
Tokyo Japanese	/k/→[ŋ]	/g/→[g]
Constriction degree and location		
Polish	/g/→[ʐ]	/dʐ/→[dʐ]

Of the thirteen identified consonantal chain shifts in our survey, nine could be separated into two articulatory dimensions, including oral constriction degree and voicing, nasality and voicing, and nasality and constriction location. Examples of each of these patterns types are provided in (5).

(17) *Two-Dimensional Chain Shifts Among Consonants*

Voicing and constriction degree		
Gran Canarian Spanish	/k/→[g]	/g/→[ɣ]
Danish	/pʰ/→[p]	/p/→[w]
Constriction location and nasality		
Kayardild	/c/→[ɲ]	/ɲ/→[n]
Toba Batak	/n/→[t]	/t/→[ʔ]

Voicing and nasality		
Irish	/p/→[b]	/b/→[m]
Mwera	/p/→[b]	/b/→[m]
Nzema	/t/→[d]	/d/→[n]
Italian	/t/→[d]	/d/→[n]
Manya	/f/→[v]	/v/→[m]

Finally, four chain shifts in our typological survey were best described as occurring along a single articulatory dimension. Most of these were alternations involving constriction degree, though one, though one involved constriction location. These are listed in (5).

(18) *One-Dimensional Chain Shifts Among Consonants*

Constriction degree		
Finnish	/k:/→[k]	/k/→[ɣ]
Florentine (fast speech)	/t:/→[θ]	/θ/→[∅]
Irish	/p/→[f]	/f/→[∅]
Constriction location		
Polish	/x/→[ʂ]	/ʂ/→[ɕ]

Overall, we observe that saltation in one-dimensional consonantal patterns appears to be unattested, or at least vanishingly rare. At the very least, one-dimensional saltations are less commonly attested among the world's languages than two-dimensional chain shifts and saltation and one-dimensional chain shifts. This lower rate of crosslinguistic attestation is predicted based on the results of the learning models reported by Smith & O'Hara (2021): phonological patterns requiring more extreme gestural blending strengths are harder to learn and therefore predicted to be less common.

Another point of interest is that one-dimensional chain shifts appear to be relatively rare, despite requiring less extreme gestural strengths than either type of two-dimensional pattern. A potential explanation for this is that one-dimensional articulatory scales are less frequently occurring than two-dimensional scales in the consonantal domain. In order for a one-dimensional consonantal lenition process to occur, for instance, there must be at least three distinct consonantal constriction degrees whose productions are tolerated by a language's phonological grammar. Such a situation is only likely to occur with certain types of consonantal gestures. For instance, there is no robust attestation of languages with consonants distinguishably produced with a closed velum, semi-open velum, and open velum. Therefore, we should not expect to observe a chain shift utilizing this single dimension. Similarly, very few languages clearly distinguish between fricatives and approximants based solely on constriction degree at each place of articulation, making a chain shift involving this distinction unlikely to occur. One-dimensional chain shifts seem to only be observable when an articulatory scale, such as constriction degree, is lengthened in some way, such as by the presence of geminate stops in the inventory of Finnish. A similar explanation may exist for chain shifts involving constriction location. Our sole attested example comes from Polish, which distinguishes three places of articulation for sibilants, allowing for a palatalization chain shift along this scale. However, such an inventory is itself fairly rare, contributing to the similar rarity of opaque patterns defined along this consonantal dimension.

On the other hand, many languages utilize multiple specifications along a single articulatory scale in their vowel inventories. In particular, many languages specify vowels for three or more distinct vowel heights. It is therefore not surprising that we see many cases of chain-shifting vowel raising and lowering along this one-dimensional scale. Conversely, vowels may be less likely to be composed of multiple gestures specified for distinct active articulators, and therefore less likely to have the gestural makeup necessary to participate in a two-dimensional chain shift or saltation. Future work will seek to quantitatively compare the typology of opaque patterns across a wide range of phonological domains while controlling for the frequency at which languages have the necessary inventory properties to develop chain shifts and saltations.

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