

*Saltation and the P-map**

Bruce Hayes

University of California, Los Angeles

James White

University College London

We define a saltatory phonological alternation as one in which sound A is converted to C, leaping over phonetically intermediate B. For example, in Campidanian Sardinian, intervocalic /p/ is realised as [β] – leaping over [b], which does not alternate. Based on experimental evidence, we argue that saltation is marked, i.e. a UG bias causes language learners to disprefer it. However, despite its marked status, saltation does occur. We survey its diachronic origins, and suggest that it is never introduced as a sound change, but arises only from a variety of historical accidents. For the formal analysis of saltation, we propose a new approach, based on Zuraw’s (2007, 2013) *MAP constraints and Steriade’s (2001, 2009) P-map. This approach is more restrictive than previous proposals, and accounts for psycholinguistic evidence indicating an anti-saltation learning bias: saltation is disfavoured during learning because it is by definition not a P-map-compliant pattern.

1 Introduction

We define SALTATION as a property of phonological alternations, as in (1).¹

(1) *Saltation*

- a. Let A, B and C be phonological segments.
- b. Suppose that for every feature for which A and C have the same value, B also has that value, but that B differs from both A and C.
- c. If in some context A alternates with C, but B remains invariant, then the alternation $A \sim C$ is a SALTATION.

* E-mail: BHAYES@HUMNET.UCLA.EDU, J.C.WHITE@UCL.AC.UK.

For help and advice we would like to thank Laura Jo Downing, Armin Mester, Viola Miglio, Russell Schuh, Norval Smith, Colin Wilson and members of audiences at the joint UCLA/USC Phonology Seminar, Harvard University and the University of Washington. We also thank our anonymous reviewers and the associate editor for their helpful input.

Supplementary materials, which include the tableaux for the complete analysis of Campidanian (see §6.3 and §6.4), are available at http://www.journals.cambridge.org/issue_Phonology/Vol32No02.

¹ We define saltation here on the basis of features for the sake of explicitness. This is not to say that features are the only way, or even the best way, to define this relationship. For instance, perceptual similarity may be an important dimension (White 2013); we return to this in §4. Other relevant dimensions may include articulatory properties, as well as abstract structure such as moras or feet. Our main arguments do not rest on knowing precisely which of these dimensions are necessary or sufficient for a definition of saltation.

An example of saltation, taken from the work of Bolognesi (1998), is given in (2). In the Sestu Campidanian dialect of Sardinian, the voiceless stops /p t k/ are lenited to [β ð γ] when they occur in intervocalic position (examples from Bolognesi 1998: 30–31, 36–39).²

(2) a. *Lenition of intervocalic /p t k/ in Campidanian*

[pif:i]	‘fish’	[bel:u βif:i]	‘nice fish’
[trintaduzu]	‘thirty-two’	[s:u ðrintaduzu]	‘the thirty-two’
[kuat:ru]	‘four’	[dɛ γuat:ru]	‘of four ...’

b. *Retention of intervocalic /b d g/ in Campidanian*

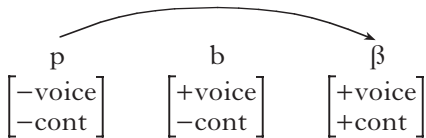
[bīu]	‘wine’	[s:u bīu]	‘the wine’
[dominiγu]	‘Sunday’	[don:ja dominiγu]	‘every Sunday’
[gɔma]	‘rubber’	[dɛ gɔma]	‘of rubber’

Bolognesi illustrates the productivity of the pattern with examples of application to borrowed or recently introduced words: [polonia] ‘Poland’ ~ [s:a βolonia] ‘(the) Poland’, [tasi] ‘taxi’ ~ [s:u ðasi] ‘the taxi’, [komput:ɛ] ‘computer’ ~ [s:u γomput:ɛ] ‘the computer’ (1998: 32–33, 463). He further notes that the output pattern is maintained consistently:

speakers ... not only do not spirantize voiced stops, but judge this ... as entirely ungrammatical, instead. For them a phrase such as, for example, *sa βɔɽta* could only be the output of underlying *sa pɔɽta* (‘the door’), and never of *sa bɔɽta* (‘the time’). They claim the second interpretation to be wrong. (1998: 36)

We adopt the term ‘saltation’ from Minkova (1993) and Lass (1997), who use it in the context of historical sound change; we discuss their claims about diachrony below. ‘Saltation’ derives from the Latin word for ‘leaping’.³ As shown in (3), underlying /p/ can be seen as leaping over intervening /b/ in arriving at [β].

(3) *The saltation path in Campidanian*



Intuitively, we can think of saltation as a case in which a non-alternating sound B is phonetically ‘intermediate’ between two alternating sounds, A and C. Although the diagram in (3) represents this relationship in a linear fashion for illustration, we are not claiming that this intermediate status must be defined on a single phonetic dimension. Indeed, by referencing

² More precisely, postvocalic onset position. The voiceless affricate /tʃ/ also spirantises (to [ʃ]), but with lexical exceptions (Bolognesi 1998: 32); we omit analysis of this segment here.

³ OED *saltate*: ‘f. L. *saltāt-*, ppl. stem of *saltāre* to dance, frequent. of *salīre* to leap’.

phonological features, our formal definition of saltation in (1) explicitly allows the intermediate sound B to be defined in terms of multiple dimensions. The Campidanian case is an example of this, as seen in (3): voiced stops are intermediate between voiceless stops and voiced fricatives on the basis of two dimensions, voicing and continuancy.

The concept of saltatory alternation has been discussed before (Łubowicz 2002, Ito & Mester 2003, McCarthy 2003) under the label ‘derived environment effects’. We prefer the term ‘saltation’ because it is theoretically neutral; it describes the data pattern rather than a proposed mode of analysis.⁴

We think that saltatory alternation is disfavoured, in the sense that a UG bias causes language learners to disprefer saltation as a hypothesis. Our support for this claim comes from experimental evidence reported in White (2013, 2014) and White & Sundara (2014).

If we are correct in claiming that saltation is marked, we must ask why it should exist at all. The answer, we claim, is that diachronically, saltation arises through a variety of accidents, involving borrowing, telescoping and similar factors.⁵ Thus it forms a classic case study for the interaction of synchrony and diachrony in phonology, a topic explored in Kenstowicz & Kisseberth (1977) and much subsequent work.

The final topic we address is finding an appropriate theoretical account of saltatory alternations. We suggest that current accounts overgenerate in serious ways, and propose an alternative based on the *MAP constraints of Zuraw (2007, 2013), which in turn is an implementation of Steriade’s (2001, 2009) P-map principle. Our account both avoids overgeneration and provides the basis for a learning bias to explain the experimental findings.

The article is organised as follows. §2 and §3 treat diachrony, arguing for the essentially accidental origin of saltatory alternations. §4 summarises the experimental evidence for a UG bias against saltation. In §5 and §6 we turn to theory, proposing an account that provides the appropriate UG bias, without leading to gross overgeneration in other domains. §7 and §8 address residual issues, and conclude.

1 Theoretical background: the classical theory of phonological change

We situate our discussion of the diachronic aspects of saltation in the context of what we will call the ‘classical’ theory of phonological change. This approach dates from the 19th century (see Anderson 1985), with continuation in more recent times in work such as Bach & Harms (1972),

⁴ Specifically, Łubowicz’s and McCarthy’s analyses relate saltation to the ‘derived environment rules’ discovered by Kiparsky (1973); our account makes no such connection.

⁵ In this respect saltation may be similar to the notion of ‘exchange rule’, a sort of ‘mutual saltation’ discussed in Anderson & Browne (1973) and related literature.

Hyman (1975), Anderson (1981), Labov (1994) and Blevins (2004). The literature is vast, and we will only give a brief overview.

The key problem is: if, as many scholars believe, the structure of phonological systems is guided by language-independent principles of markedness, how is it that phonological systems can attain unnatural states? Such cases seem to arise especially often for patterns of alternation; in (4) we offer some cases from the literature.

(4) *Some plausibly unnatural phonological alternations*

- a. Odawa palatalisation: /n/ → [ɲ] in front contexts (Kaye 1978, Buckley 2000).
- b. Open syllable shortening and closed syllable lengthening in Menomini (Hayes 1995: 218–221, Buckley 2000).
- c. Epenthesis of unexpected consonants such as [ɹ] (Vaux 2002).

In the classical model, the origin of such unnatural alternations lies in a bifurcation of the sound system into phonetic processes and phonological processes.⁶ The phonetic processes constitute the primary engine driving diachronic change, and are normally subphonemic, involving continuous variation along phonetic continua (e.g. height, rounding). Synchronically, they create free variation, and often reflect stylistic preferences. Phonetic change is seen as natural, involving for instance lengthening of stressed vowels, lenition of intervocalic consonants, palatalisation before front vowels, and so on. Gradient phonetic effects may act as precursors to phonological processes; for instance, /VpV/ may be pronounced more and more similarly to [VbV] over time, due to the voicing present in adjacent vowels, which may itself lead to a phonologised process of intervocalic stop voicing (e.g. Hyman 1975: 172–173, Blevins 2004, Moreton 2008).

The essential premise of the classical approach is that (at least to some degree) phonetic processes are *indifferent to the consequences incurred by the higher-level phonological system*; for explicit defence of this idea see Labov (1994). As a result, phonetic change, particularly as it accumulates over time, can end up creating patterns that are unnatural when construed in synchronic terms.⁷ The phenomenon is sometimes referred to under the rubric of ‘telescoping’ (Hyman 1975, Kenstowicz & Kisseberth 1977). To give one example, the gradual changes that led to the modern pronunciation of Middle English long [i:] as [aɪ] led to the phonetically extreme

⁶ Other versions of the classical approach adopt different distinctions, e.g. the 19th-century distinction of sound change *vs.* analogy, Baudouin de Courtenay’s ‘neophonetic’ *vs.* ‘paleophonetic’ alternations (Anderson 1985: 73), the ‘processes’ *vs.* ‘rules’ of Natural Phonology (Stampe 1973) or the postlexical–lexical distinction made in Mohanan’s (1982) version of Lexical Phonology.

⁷ We do not advocate a Neogrammarian conception of sound change as fully blind to linguistic structure (a view appropriately criticised in Kiparsky 1965 and later work); for our purposes it need only be true that phonetic change is ‘blind enough’ to create synchronic conundrums as changes accumulate.

alternation of [aɪ] ~ [ɪ] (Dobson 1968: 659–662) in Modern English trisyllabic shortening alternations such as such *divine* ~ *divinity*. In another case, Kenstowicz & Kisseberth (1977: 64–65) describe how Ukrainian acquired the process [o] → [i] in the environment / __ C#: roughly, final [oC-r#] and [oC-ʊ#] evolved to [o:C#] (apocope with compensatory lengthening), then [y:C#] (fronting and raising), then [iC#] (unrounding and loss of phonemic length), while other forms in the paradigm of [oC-V#] stayed unchanged. All the processes that were telescoped were natural, but the end result hardly so.

The telescoping of phonetic changes represents a common way in which languages acquire unnatural phonological patterns. However, the new generations that get exposed to the pattern in childhood are not always passive replicators, but sometimes engage in RESTRUCTURING, i.e. imperfect phonological learning that creates a novel pattern (see e.g. Kiparsky 1965, Kenstowicz & Kisseberth 1977: 65–77). One classical case of this kind is rule inversion (Kiparsky 1965: 1–11, Vennemann 1972a), of which a famous example has occurred in most non-rhotic dialects of English: what was originally a deletion alternation (*sore* [sɔ:] ~ *sore* as [sɔ:ɪ æz] was restructured as epenthesis, and thus extended to ahistorical cases like *saw* [sɔ:] ~ *saw* it [sɔ:ɪ ɪt]). The reanalysis of formerly stem-final consonants as epenthetic consonants – the inversion of the historical deletion process – is indeed suggested by Vaux (2002) as a common source of ‘unnatural’ forms of epenthesis. Rule inversion is not the only kind of restructuring; other cases include those treated by Kiparsky (1965, 1982) as rule reordering, as well as paradigm levelling, which can be sporadic (e.g. English *fungi* [ˈfʌŋɡaɪ] for historical [ˈfʌŋdʒaɪ]), or occasionally across the board, with massive changes across the entire vocabulary (see Bowers’ 2012 account of such a change in Odawa).

In sum: the classical theory explains the great variety of natural and unnatural phenomena through a dual bifurcation. At the synchronic level, the essential bifurcation is that of phonetic *vs.* phonological patterning, with a degree of independence of the former from the latter; this is the seed for the long-term creation of unnatural patterns. Diachronically, the bifurcation is between the cumulative effects of phonetic change on the one hand and grammar change on the other.

3 The historical origin of saltation

How does saltation fit into the classical theory? The first point is that it is unlikely that a saltatory alternation could arise in the simplest possible way, namely as emergence of a single sound change into the phonological system. The reason is straightforward: if (using the format of (1)) sound A gradually drifted in the direction of C, it would trigger a neutralisation with intervening B. This point is asserted by Minkova (1993), Labov (1994) and Lass (1997), all of whom who suggest that single sound changes are never saltatory.

If saltation cannot arise from a single unidirectional sound change, then how do saltatory patterns come to be? By studying the cases we could locate, we have arrived at a simple taxonomy of the origins of saltation, given in (5).⁸

(5) *Origins of saltation: a taxonomy*

a. *Interposition by borrowing*

A becomes C in some context; B is later interposed when acquired as a new phoneme in loanwords.

b. *Interposition by grammar change*

A becomes C in some context; B is later interposed as a result of grammar change.

c. *Flanking*

A was originally something else (A') that became C in the alternation context, then A' changed to A in the non-alternation context. A and C now flank B, forming a saltation.

We elaborate these three cases below with examples.

3.1 Interposition by borrowing

A case of this type is described by Ito & Mester (2003) for Standard German: in final position following atonic [ɪ], /g/ surfaces as [ç] (the allophone of /x/ found after front vowels), as in /'kø:nig/ → ['kø:nɪç] 'king' (cf. ['kø:nɪgə] 'kings'). Yet underlying /k/ in this position is invariant: ['plastɪk] 'plastic'. The sounds [g] and [ç] differ in voicing, continuancy and place of articulation; [k] differs from [g] in voicing, and from [ç] in continuancy and place; hence by definition (1) the alternation is saltatory.

Inspection of the cases with [k] after atonic [ɪ] shows that they are cosmopolitan words; Ito & Mester give examples like *Plasti*[k] 'plastic', *Derri*[k] (name of television detective) and *Bati*[k] 'batik', patently recent loanwords in German.⁹ The likely reason that [k] had previously been missing finally after stressless [ɪ] was because earlier historical [k] had been converted to [x] by the Second German Consonant Shift; see e.g. Salmons (2012: 116).

Interposition by borrowing also characterises two other saltations reported by Łubowicz (2002). In Slovak (Rubach 1993), the sounds [e o] alternate in a variety of contexts with the diphthongs [ie uo], thus saltating over [e: o:] ([e: o:] share their vowel qualities with [e o] and their status as heavy nuclei with [ie uo]). The long mid vowels are originally almost entirely from loanwords of the usual pan-European character such as [majonez] 'mayonnaise' (Rubach 1993: 177). Łubowicz reports a similar

⁸ The change from A to C, both here and in (5b), should not be construed as a leap; rather we assume that it represents the telescoped result of what may have been a whole series of minor changes.

⁹ With help from Armin Mester, we have verified this generalisation using the Leipzig Online Dictionary, available at <http://wortschatz.uni-leipzig.de>.

case in Polish: here, underlying /g/ surfaces as [ʒ] before front vowels, skipping over intermediate [dʒ] ([g] and [ʒ] differ in continuancy, stridency and place of articulation; [dʒ] differs from [g] in stridency and place and from [ʒ] in continuancy); thus /vag+i+tɕ/ → [vaʒ+i+tɕ] ‘to weigh’, but /bridʒ+ik+i/ → [bridʒ+ek], not *[briʒ+ek] ‘bridge (card-game) + DIM’. The forms with invariant [dʒ] are evidently pan-European loans, like the word for ‘bridge’ (see Rubach 1984: §5.3, Łubowicz 2002: 245). We see these cases as showing that, at least in some instances, the pressure to be faithful to a foreign-language source can override whatever system-internal pressure there may be (see §4 below) to avoid saltation within the synchronic system.

3.2 Interposition by grammar change

We argue that Campidanian (§1) likewise is a case where B was interposed between a pre-existing alternation of the form A → C. But the mechanism is more interesting: it arose from grammar change. In our proposal, the Campidanian pattern originated as an ordinary lenition chain, shown schematically in (6).

$$(6) \left\{ \begin{array}{l} p \rightarrow b \rightarrow \beta \\ b \rightarrow \beta \rightarrow \emptyset \end{array} \right\} / V _ V$$

That is to say, historical [p b] (and similarly [t d] and [k g]) weakened intervocally, while remaining distinct, along the same lenition path. [b], being in the lead, was the first to reach the extreme of full deletion. This was a radical step, in that it created extensive neutralisation (all three voiced stops) in a sensitive place, i.e. stem-initial position (see Beckman 1997, 1998, Casali 1997, Becker *et al.* 2012).¹⁰ We conjecture that when this merger became phonetically complete, the language reached a crisis stage, resolved when a new generation of children refused to accept the extreme alternation, and ‘fixed’ the language by restoring the isolation allomorphs postvocally. Our scenario is summarised in (7) for the forms for ‘nice fish’ and ‘the wine’.

(7) <i>initial stage</i>	bɛ:u [p]i:fi	s:u [b]i:u
<i>early lenition</i>	bɛ:u [b]i:fi	s:u [β]i:u
<i>crisis stage:</i>		
<i>massive stem-initial neutralisation</i>	bɛ:u [β]i:fi	s:u [∅]i:u
<i>post-crisis stage:</i>		
<i>restructuring</i>	bɛ:u [β]i:fi	s:u [b]i:u

¹⁰ In principle, there would have been merger with the historically vowel-initial words as well. However, as Bolognesi notes (1998: 216), historically vowel-initial words trigger hiatus-resolution processes when a vowel-final word precedes them, whereas words derived from initial /b d g/ – like the *h-aspiré* words of French – typically do not.

In defending this scenario, we first address *whether* the conjectured events happened; then, assuming that they did, we speculate on *why* they happened.

Concerning the factual accuracy of the scenario, we first note that, as Bolognesi points out (1998: 36, citing Virdis 1978), there are neighbouring dialects of Sardinian where the hypothesised early lenition stage in (7) is still attested; that is, voiced stops are still realised as voiced fricatives intervocally. This increases the plausibility that Campidanian also went through such a stage.

Second, historical evidence indicates that the voiced stops that were intervocalic *within morphemes* in Campidanian disappeared entirely (Bolognesi 1998: 212). The examples in (8) (from Bolognesi 1998: 24, 31, 189) illustrate this.

- | | | | |
|-------------|-----------|--------------|--------|
| (8) [teula] | 'shingle' | Latin TEGULA | 'tile' |
| [kɔa] | 'tail' | Latin CAUDA | |
| [nuu] | 'knot' | Latin NŌDUS | |
| [taula] | 'board' | Latin TABULA | |

This is to be expected under our account, since a medial voiced stop would not have any other allomorph from which the underlying form could be recovered. In historical linguistics, such relic monomorphemic forms constitute a classical diagnostic for the scenario of sound change followed by grammar change; for examples see Kiparsky (1968: 176–179), King (1969: 46–48), Vennemann (1972b) and Bynon (1977: 144).

Third, Bolognesi notes the existence of particular words beginning with voiced stops that, even in contemporary Campidanian, alternate optionally with zero, as in (9) (from Bolognesi 1998: 37).

- | | | | |
|--------------|---------|------------------------------|-------------|
| (9) [bak:ɪa] | 'cow' | [s:ɪa bak:ɪa] ~ [s:ɪa ak:ɪa] | 'the cow' |
| [dɔmu] | 'house' | [s:ɪa dɔmu] ~ [s:ɪa ɔmu] | 'the house' |
| [gat:u] | 'cat' | [s:u gat:u] ~ [s:u at:u] | 'the cat' |

Such alternation is allowed only in 'a restricted number of lexical items' (1998: 190), forming a 'closed class' (1998: 215). Other words do not allow alternation at all, as in (10) (from Bolognesi 1998: 37).

- | | | | |
|---------------|---------------------------------------|------------------------------|---|
| (10) [bar:ɪa] | 'drill' | [s:ɪa bar:ɪa], *[s:ɪa ar:ɪa] | 'the drill' |
| [dɔt:ori] | 'doctor' | [s:u dɔt:ori], *[s:u ɔt:ori] | 'the doctor' |
| [gaupɔʒu] | 'food that
can be put
on bread' | [s:u gaupɔʒu], *[s:u aupɔʒu] | 'the food that
can be put
on bread' |

An examination of the data throughout Bolognesi's work suggests the following generalisation: alternators tend to be words of the core vocabulary, with glosses such as 'of', 'want', 'road', 'house', whereas non-alternators are from more sophisticated vocabulary, with glosses such as 'doctor',

‘drill’, ‘rubber’, ‘chicory’. We suggest that the alternating forms are relics, dating from the time when intervocalic deletion of voiced stops applied across the board; in this respect they resemble English *kept*, a relic dating from when pre-cluster shortening was applicable across the board in English. As with relic forms elsewhere in historical phonology, they skew toward the core vocabulary, since it is in core vocabulary that relic forms tend to be retained over time (Bynon 1977: 42–43, Bybee 1985: 119–120).

A further remarkable property of the relic alternating forms is that their \emptyset -initial allomorphs are employed in *careful*, not fluent, speech (Bolognesi 1998: 36–37); this may reflect the demands of lexical retrieval for listed forms.¹¹

Thus, if the arguments just given are correct, Campidanian saltation was never a sound change; rather, it involved interpolation of the voiced stops in the intermediate position by grammar change. We return to the formal analysis of Campidanian below (§6), as well as the question of why the grammar change took place as it did (§7).

A second instance of saltation through grammar change is offered by Itô & Mester (1997). In the *rendaku* (compound voicing) alternations of Conservative Tokyo Japanese, basic /k/ saltates over /g/ in becoming [ŋ], as in /ori+kami/ → [oriŋami] ‘folding paper’. That the alternation is saltatory is shown by forms like /niwa+geta/ → [niwaŋeta] ‘garden clogs’.¹² The historical evolution of this pattern is plausibly as follows: (a) [k] was originally voiced by *rendaku* to [g], in parallel with other obstruents; (b) [g] then further evolved to [ŋ] intervocalically in the Conservative Tokyo dialect; (c) lastly, [g] was optionally restored in paradigms (grammar change). As Itô & Mester suggest, this could have arisen through promotion of an output-to-output correspondence constraint (Benua 1997) requiring an exact match to [g] in the base form, as in [niwaŋeta]. No base form with [g] is available for [oriŋami], which accounts for its invariant [ŋ].

3.3 Flanking

Ito & Mester (2003) report a saltation in certain northern varieties of German in which the surface form of underlying /g/ in final position is not the expected [k] (via the well-known process of final devoicing) but rather [x], as in [fra:x] ‘asked (1SG)’ (cf. [fra:ŋən] (1PL)). Since there are

¹¹ An issue we will not treat in detail is how the irregular forms of (9) should be analysed in a formal grammar. They do not seem fundamentally different from any other forms of lexical allomorphy, and appropriate theoretical apparatus has been proposed in the literature; see e.g. Mascaró (1996) and McCarthy’s (2004) appended commentary for further references. Following this tradition, we suggest that words of the class in (9) have dual lexically listed allomorphs, such as {/bak:a/, /ak:a/}, and that the appropriate allomorph is selected (sometimes in free variation) by the constraint system.

¹² The latter form may also be pronounced [niwaŋeta]; hence the alternation is not *invariably* saltatory.

also non-alternating forms with [k] (e.g. [dik] ‘fat’; inflected [dik-ə]), this is saltation of /g/ to [x] over [k].

A plausible origin for this case is described by Robinson (2001), relying on earlier work by Schirmunski (1962) and Pilch (1966): it appears to be not a consequence of sound change but of hypercorrection. In vernacular varieties of North German, earlier [g] evolved into the spirant [ɣ]¹³ whenever it followed a vowel, including intervocalically (Schirmunski 1962). For these vernacular varieties, sample paradigms would have evolved as in (11).¹⁴

(11) *North German saltation (phase I): the vernacular dialects*

	<i>fragen</i> ~ <i>frag</i> ‘ask (IMP ~ INF)’	<i>dicke</i> ~ <i>dick</i> ‘fat (INFL ~ PLAIN)’	<i>machen</i> ~ <i>mach</i> ‘do (IMP ~ INF)’
<i>pre-North German</i>	g ~ g	k ~ k	x ~ x
<i>spirantisation of</i> g <i>after vowels</i>	ɣ ~ ɣ	k ~ k	x ~ x
<i>final devoicing</i>	ɣ ~ x	k ~ k	x ~ x

According to Pilch (1966), North German varieties are subject to normative influences; he mentions the social ‘pressures of educated society’. This influence has given rise to a variety that Pilch calls ‘Refined’ (*vornehm*) North German, exemplified by the paradigms in (12).

(12) *North German saltation (phase II): refined varieties*

<i>fragen</i> ~ <i>frag</i>	<i>dicke</i> ~ <i>dick</i>	<i>machen</i> ~ <i>mach</i>
g ~ x	k ~ k	x ~ x

As can be seen, in Pilch’s Refined North German – which is in fact the variety Ito & Mester describe¹⁵ – [ɣ] is replaced (either optionally or obligatorily) by the normative form [g]; thus *fra*[g]*en* instead of *fra*[ɣ]*en*. Less often, Pilch notes, Refined speakers also southernise forms like *fra*[x] to *fra*[k]. Yet it would seem easier to cleanse one’s speech of all [ɣ]’s by replacing them with [g] (via a surface, perhaps postlexical operation) than to ‘fix’ only the [x]’s that derive from /g/ with [k]. When a speaker makes the easy repair but not the hard one, the resulting pattern is the saltation seen in (12).

The realism of this scenario is further increased by the existence of speakers (Armin Mester, personal communication) who produce the Refined North German variants in careful, public contexts, but the vernacular forms in casual contexts with family and friends.

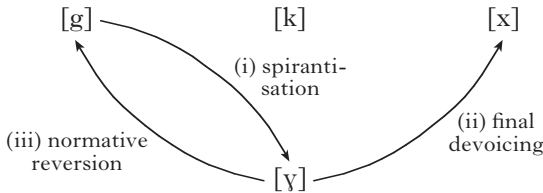
¹³ Or its partner [j] in the environment after front vowels (Robinson 2001: 91); velar examples are used here for simplicity.

¹⁴ These forms are schematic and not guaranteed to match actual dialect data.

¹⁵ We will not venture to reconcile Pilch’s calling the same variety ‘Refined’ that Ito & Mester call ‘Colloquial’; perhaps standards of refinement have risen during the four decades separating these works.

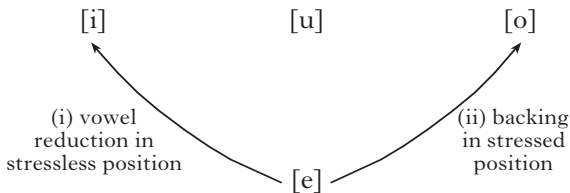
From the diachronic perspective, it can be seen that Refined North German acquired a saltatory alternation through a sort of flanking manoeuvre, as seen in (13): on one flank, historical [g] evolved into [ɣ], thence (in final position only) into [x]. This in itself did not produce saltation; however, a reverse change, the normatively driven shift of [ɣ] back to [g], moved the alternating pair [g] ~ [x] into a saltatory arrangement with respect to [k]. As with previous cases, saltation was not a direct historical innovation.

(13) *Formation of North German saltation though flanking*



Crosswhite (2000) offers another case of saltation from Russian that likewise can be considered as a case of flanking. Here, phonemic stressless /o/ is reduced to [i] when following a palatalised consonant (and not immediately pretonic), with phonemic stressless /u/ remaining as [u] in the same environment. Since [u] is high like [i] and back and rounded like [o], this is saltation. Crosswhite gives the diachronic background: ‘this unusual pattern of /o/ > [i] but /u/ > [u] derives historically from the fact that stressed /e/ became [o] when preceded by a palatalized consonant but not followed by one: CêC > CôC’. In our terms, this is saltation by diachronic flanking, as shown in (14).

(14) *Formation of Russian saltatory vowel reduction though flanking*



Crosswhite also presents evidence that the Russian saltation pattern is no longer productive (at least in certain dialects): it fails to apply to real words newly introduced into Russian, it was emphatically rejected by native speakers in a nonce-word test conducted by Crosswhite and it gives rise to regularising shifts in the pronunciation of existing words. These facts will be relevant below when we consider the synchronic analysis of saltation.

To sum up our historical survey: the data so far given seem compatible with the view that saltation is never the result of a single sound change, but always of secondary factors such as borrowing, telescoping or restructuring.

3.4 Further saltatory alternations

We cover four further cases; these examples constitute all the instances of saltatory alternation of which we are aware.

3.4.1 *Manga Kanuri*. The Manga dialect of Kanuri (Schuh 2003, 2005, Jarrett 2007) constitutes the biggest puzzle for our view that saltation cannot arise directly from sound change. In this language, basic /t/ surfaces as [ð] when between two sonorants, saltating over [d], which is invariant in this position. Historically at least, [ð] was an allophone (non-contrastive variant) of /t/, much as in Campidanian. There are also alternations that persist today, as with the nominaliser prefix /kən-/; as in [tâ] ‘catch (vb)’ ~ [kəndâ] ‘catch (N)”; [dóndi] ‘sick’ ~ [kəndóndi] ‘sickness’.

Similarly to the Russian example just given, the Manga Kanuri pattern seems to be breaking down: intervocalic [t] is now phonologically legal in the language and thus contrasts with /ð/; this is attested by about 24 stems with intervocalic [t] in the dictionary of Jarrett (2007), occurring both in European loans and otherwise.

Concerning the history of saltation in Manga Kanuri, we note a particularity of this dialect, namely that the region in which it is spoken was not originally Kanuri-speaking: historically, Kanuri spread westward into areas populated by speakers of Chadic languages, of which Bade and Ngizim still survive as near-islands, now separated from one another by a Kanuri-speaking area (Hutchison 1981: 4, Schuh 2003, 2005). Both Bade and Ngizim include implosive [ɗ] in their phoneme inventories, making it reasonable to suppose that this was also true of the now-extinct Chadic varieties that were displaced by Kanuri. Our conjecture is that the Chadic speakers who first adopted Kanuri rendered Kanuri [d] with their own implosive [ɗ].¹⁶ If this [ɗ] was still in place when [t] lenited to [ð] between sonorants; then it was not on the direct path between [t] and [ð] (neither of which are implosive) and the change was therefore not saltatory. Ultimately, the hypothesised Chadic-influenced variety of Kanuri lost [ɗ], shifting it to [d] in conformity with other Kanuri dialects. Thus [d] was interposed between [t] and [ð] (cf. §3.1 and §3.2 above), creating the saltation. This account of Manga Kanuri saltation is speculative, and the matter deserves further attention.

3.4.2 *Suma*. Discussing the tonal phonology of Suma, Bradshaw (1995, 1998, 1999) indicates that in the associative construction of this language, a final low tone becomes high when it is preceded by a high tone, resulting in an alternation between a HL pattern and a HH pattern. Bradshaw states that ‘nouns with final H or M tones do not alternate’ (1998: 117); however, no examples of this type are given, nor are the possible historical origins of the claimed saltation discussed.

¹⁶ For an instance where implosives have been employed in loan adaptation of foreign words with voiced stops, see Smith & Haabo (2007) on Saramaccan.

3.4.3 *Makassarese*. McCarthy (2003) offers what may be an additional example of saltation from Makassarese (Aronoff *et al.* 1987), namely $/\{r\ l\ s\}\#\#/ \rightarrow [\{r\ l\ s\}V\#\#]$, with a form of glottal epenthesis that is not found for simple underlying final vowels (i.e. $/V\#\#/ \rightarrow [V\#\#]$). This would be an interesting case of saltation, because it involves segment sequences, not individual segments, and thus falls outside the scope of the definition in (1). The case for saltation here is not ironclad, however, because the contexts of the two changes are different: given the Makassarese stress pattern, stable final $[V]$ is always directly posttonic, whereas derived final $[V\#]$ occurs only when there is antepenultimate stress. Inkelas (1999: 145) and Anttila (2012: 87) have suggested constraints that forbid heavy syllables in clash; if present in Makassarese, such constraints could independently block the appearance of $[p]$ for underlying final $[V]$; i.e. $['CVCV\#]$ from $/CVCV\#/$ would be clashing, $['CVCVCV\#]$ from $/CVCVCV\#/$ would not.

3.4.4 *A second saltation in Campidanian*. Campidanian also saltates voiced geminates $/b\ d\ g\:/$ to $[\beta\ \delta\ \gamma]$ crossing over $[b\ d\ g]$; this saltation is discussed in §6.4 below.

3.5 Local summary

As summarised in §2, the classical framework of phonological change provides a plausible account of the origin of unnatural phonological alternations via telescoping and restructuring. We have supported the view, expressed by Lass, Minkova and Labov, that there is no need to appeal to saltatory sound changes to explain the existence of synchronic saltatory alternations. Indeed, saltatory alternations appear to constitute a classic illustration of the variegated ways in which telescoping and restructuring can give rise to surprising synchronic patterns, just as the classical theory maintains.

4 Evidence for a learning bias against saltation

We turn now to synchrony, asserting that saltation is a marked phenomenon, disfavoured as a hypothesis by language learners. In making this claim, we cannot rely on a traditional source of evidence in phonology, namely the rarity of a phenomenon across languages. Should saltation be rare (we suspect it is, but our data do not suffice to prove it), we already have an explanation, namely that it requires exceptional diachronic circumstances to come into being. Instead, the evidence must come from direct observation of language learners. For instance, we might expect that children learning Campidanian would have difficulty, making errors such as converting $/b\:/$ to $[\beta]$ in intervocalic position.¹⁷ Sadly, it would be difficult to verify this point, since it appears that very few, if any, young children are still learning this language (Bolognesi 1998: ch. 1).

¹⁷ Bolognesi (1998: 36) reports that Campidanian-speaking adults make this error, but only rarely.

A more feasible research path is to test the acquisition of saltatory patterns in artificial language learning experiments. Recent work in this area has yielded results that suggest that saltation is indeed difficult to learn. White (2013, 2014) exposed adult English-speaking participants to an artificial language containing phonological alternations comparable to those seen in Campidanian: voiceless stops ([p t]) changed to voiced fricatives ([v ð]) intervocalically, but voiced stops ([b d]) did not alternate. Despite their training, participants frequently spirantised voiced stops in error when tested on novel forms. Control conditions indicated that the errors were due to an anti-saltation effect, and not merely to factors such as rule overgeneralisation or product-oriented learning.

Indeed, the same pattern emerges in experiments on infants. White & Sundara (2014) exposed 12-month-old infants to potentially saltatory alternations (e.g. [p ~ v]) in an artificial language; infants who learned the [p ~ v] alternation generalised to [b ~ v], but not *vice versa*. Further, Sundara *et al.* (2013) show that American English-learning infants acquire the [d ~ r] alternation (*pad* ~ *padding*), but not the [t ~ r] alternation (*pat* ~ *padding*), by twelve months. Sundara *et al.*'s corpus search revealed that there is greater statistical evidence for the [t ~ r] alternation in infants' language input, suggesting that the earlier acquisition of the [d ~ r] alternation is due to a learning bias. These results are consistent with our proposal that saltation is dispreferred: if infants had instead learned the [t ~ r] alternation before the [d ~ r] alternation, this would be a saltation, because [d] is intermediate between [t] and [r] by our definition in (1).

In some instances, data from language change also suggest that saltation may be dispreferred during learning: as already mentioned (§3.3), Crosswhite (2000) documented ongoing synchronic breakdown of the Russian [o] – [u] – [i] saltation, and in Manga Kanuri (§3.4.1) the formerly allophonic relationship of [t] and [ð] has broken down with the admission of new forms with intervocalic [t]. Yet we cannot always expect to see such traces: it may well be that adult speakers of languages with saltation are often exposed to such extensive data that they do learn their language successfully; in particular we noted in §1 Bolognesi's argument that Campidanian saltation is productive.

A striking case of acquisition error may be evident in the spirantisation pattern of Logudorese, a Sardinian dialect related to Campidanian (Ladd & Scobbie 2003). Here, the same kind of relic forms noted in §3.2 above for Campidanian ([^hbak:a] ~ [sa 'ak:a]) demonstrate that in this dialect voiced stops originally lenited to zero intervocalically, just as they did in Campidanian. But the innovating (and probably productive) pattern in contemporary Logudorese is to lenite underlying intervocalic /b d g/ to [β ð γ], neutralising them with underlying /p t k/; thus [du'tɔ:ɾɛ] 'doctor' ~ [su ðu'tɔ:ɾɛ] 'the doctor' neutralised with /t/ in ['tɛra] 'land' ~ [sa 'ðɛra] 'the land'.¹⁸ It is tempting to suppose Logudorese ancestrally

¹⁸ Our transcriptions give [β ð γ], but these are actually in free variation with [b d g], perhaps indicating that historical /p t k/ did not lenite as far in Logudorese as in

had the same pattern as Campidanian, and evolved into its current state by precisely the kind of acquisition error committed by White's experimental subjects.

In sum, evidence from recent experimental work with adults and infants as well as historical change suggests that saltatory patterns are difficult to learn or otherwise dispreferred by learners.

5 Synchronic theories of saltation: earlier accounts

We turn now to theoretical approaches to the synchronic analysis of saltation. The discussion above offers possible criteria of adequacy for such analyses. Whatever theory we adopt should include some element to which we can attach the imputation of difficulty in learning, in order to be able to explain the experimental and language-change evidence just adduced. More straightforwardly, the theory should predict that saltation is at least *possible*; since it appears that on occasion, when historical change dishes up a saltatory pattern, language learners have been able to maintain it productively for some period of time.

We will also invoke one further criterion of adequacy, namely restrictiveness. In general, phonologists have sensibly preferred theories that do not allow the generation of bizarre patterns unattested in the world's languages; and we will invoke this form of argument in assessing the theories reviewed below.

5.1 Why saltation cannot be derived in classical Optimality Theory

We begin by repeating the arguments of Łubowicz (2002) and Ito & Mester (2003) that saltation cannot be derived in 'classical' Optimality Theory. By the latter we mean Prince & Smolensky (1993), as modified by the Correspondence Theory of McCarthy & Prince (1995).

Consider first Campidanian. When /p t k/ shift to [β δ γ] in intervocalic position, they become voiced; in standard OT this will follow if a markedness constraint banning intervocalic voiceless sounds (*V[-voice]V) outranks the opposing faithfulness constraint for voicing, IDENT[voice]. In addition, when shifting to [β δ γ], /p t k/ become [+continuant]. This will follow if a markedness constraint banning intervocalic stops (*V[-cont]V) outranks the opposing faithfulness constraint for continuancy, IDENT[cont]. As shown in (15), a grammar that respects these rankings will generate [aβa] from underlying /apa/ for the bilabial case.¹⁹

Campidanian. The essential point is that, unlike in Campidanian, Logudorese /p t k/ and /b d g/ are neutralised intervocalically, eliminating the saltation.

¹⁹ To save space we use schematic underlying forms with the vowel /a/ only; these are meant to represent actual data such as those presented above in §1.

(15)

/aba/	*V[-vce]V	*V[-cont]V	Id[vce]	Id[cont]
a. aβa			*	*
b. aba		*!	*	
c. aφa	*!			*
d. apa	*!	*		

However, since V[-cont]V outranks IDENT[cont], /aba/ will likewise surface as [aβa], as in (16), which is incorrect.

(16)

/aba/	*V[-vce]V	*V[-cont]V	Id[vce]	Id[cont]
a. aβa				*
b. aba		*!		
c. aφa	*!		*	*
d. apa	*!	*	*	

Thus there is a ranking contradiction: V[-cont]V must outrank IDENT[cont] in order to let /p/ go all the way to [β], but IDENT[cont] must outrank V[-cont]V in order to keep intervocalic /b/ unaltered.

Now consider the general case, A → C with intermediate unchanging B. The rankings that send A to C will also wrongly send B to C, for given our definition of saltation in (1), the faithfulness violations incurred in changing B to C are a subset of those incurred in changing A to C. Thus, the faithfulness constraints cannot prevent B from changing to C. Moreover, the same end cannot be achieved by assigning a sufficiently low ranking to the markedness constraints that favour changing B to C; under this strategy, A would wrongly change to B rather than C. Such considerations suggest that analysing saltation is, in general, beyond the scope of classical OT.

5.2 The constraint-conjunction approach

If classical OT cannot treat saltation, what can? Łubowicz (2002) proposes to employ LOCAL CONSTRAINT CONJUNCTION, in the sense of Smolensky (1995).²⁰ This solution was adopted by Crosswhite (2000) for Russian and by Ito & Mester (2003) for German. The crucial idea is to conjoin a markedness constraint with a faithfulness constraint, which for Campidanian would work as in (17).

(17) *IDENT[voice] & *V[-cont]V

²⁰ Specifically, we mean constraints that penalise candidates that are simultaneously ‘bad in two respects’; for the alternative of penalising candidates that are bad in either of two respects, see Crowhurst & Hewitt (1997), Downing (1998) and Crowhurst (2011).

This constraint says that a segment should not be simultaneously unfaithful (with regard to IDENT[voice]) and marked (with regard to *V[-cont]V). Intuitively, this can be expressed as: ‘do not have an intervocalic stop that already violates faithfulness to [voice]’. Under this set-up, intervocalic /p/ cannot surface as [b], though voicing-faithful /b/ is allowed to do so. (18) gives tableaux illustrating this point.

(18) a. *Conjoined constraint forces /p/ → [β]*

/apa/	Id[vce] & *V[-cont]V	*V[-vce]V	Id[vce]	Id[cont]	*V[-cont]V
i. aβa			*	*	
ii. apa		*!			*
iii. aba	*!		*		*

b. */b/ is stable*

/aba/	Id[vce] & *V[-cont]V	*V[-vce]V	Id[vce]	Id[cont]	*V[-cont]V
i. aba					*
ii. aβa				*!	

However, as originally pointed out by Itô & Mester (1998), the cost of this solution for phonological theory as a whole is extremely high: it leads to a broad licence for marked entities to be favoured over unmarked ones, contrary to typology. We demonstrate this here with our own example, constructing a hypothetical language whose phonology is highly implausible.

We assume some garden-variety constraints: (a) a markedness constraint, *[-son, +voice], banning voiced obstruents (e.g. Lombardi 1999), (b) an opposing faithfulness constraint, IDENT[voice], (c) a markedness constraint, *CCC, banning triple consonant clusters²¹ and (d) an opposing faithfulness constraint, MAX(C). We assume that our language in the normal case forbids voiced obstruents (as in Hawaiian and other languages), and hence employs the ranking *[-son, +voice] ≫ IDENT[voice]. We also assume that our language permits triple clusters, so that MAX(C) ≫ *CCC. Now we conjoin markedness and faithfulness constraints to create IDENT[voice] & *CCC, and rank the resulting constraint above *[-son, +voice]. The result is that in our hypothetical language, voiced obstruents are allowed, but only when they occur as part of a triple cluster. The tableaux demonstrating this are given in (19).

²¹ This could be replaced by syllable-based constraints; the point of our example would not change.

(19) a. *Voiced obstruents disallowed in simple cases*

/ba/	Id[vce] & *CCC	MAX(C)	*[-son,+vce]	*CCC	Id[vce]
i. pa					*
ii. ba			*!		

b. *Voiced obstruents allowed in triple clusters*

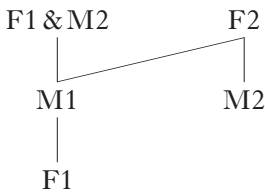
/apdka/	Id[vce] & *CCC	MAX(C)	*[-son,+vce]	*CCC	Id[vce]
i. apdka			*	*	
ii. apka		*!			
iii. aptka	*!			*	*

We certainly know of no language that permits voiced obstruents only in triple clusters, and do not expect to encounter one. At the very least, it is grossly counterintuitive to think that appearance in a highly marked configuration (CCC) would permit the appearance of otherwise illegal segments.

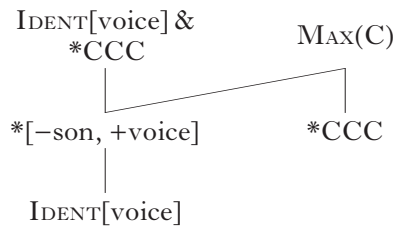
The example can be generalised as follows. Assume two markedness constraints, M1 and M2, which are independent and can be violated in the same location. In general, violations of M1 are not allowed, because M1 dominates the opposing faithfulness constraint, F1. Moreover, F2 is ranked above both M1 and M2, meaning that violations of these markedness constraints cannot be resolved by violating F2. Finally, a conjoined constraint, F1 & M2, dominates M1. The result will be a language in which M1 can be violated only when M2 is also violated. For comparison, the rankings for both the general scheme and its specific instantiation above are given in (20).

(20) *A problematic constraint ranking*

a. *General scheme*



b. *Specific example from (19)*



The general scheme can be cashed out as a panoply of bad typological predictions, for instance the existence of languages in which nasalised low vowels are confined to stressless syllables, front rounded vowels occur only in hiatus, contour tones are limited to creaky vowels, and so on. It is patently the case in phonology that adding a marked context does not make it easier to violate a markedness constraint; often it makes it harder (which is why conjoined markedness constraints often make

sense; Ito & Mester 2003). For this reason, we feel that it would be sensible to ban markedness–faithfulness conjunctions from phonological theory entirely; this is proposed by Ito & Mester (1998: 13) under the title ‘restriction on conjoinability’.²²

5.3 The comparative markedness approach

Another earlier approach to saltation is provided by McCarthy (2003), who includes saltation among the phenomena to be treated in his proposed theory of comparative markedness. Under this approach, each markedness constraint M is replaced with two constraints, ${}_O M$ and ${}_N M$. ${}_O M$ only assesses markedness violations that are ‘old’, meaning that the violations are present in the fully faithful candidate.²³ ${}_N M$ only assesses markedness violations that are ‘new’, meaning that the violations are *not* present in the fully faithful candidate. ${}_O M$ and ${}_N M$ may be freely ranked within the constraint hierarchy. It is easy to see that this scheme could give rise to saltation: in cases where A saltates over B to C , high-ranked $*{}_N B$ forces underlying A to surface as C , whereas low-ranked $*{}_O B$ permits underlying B to remain in place.

Applied to Campidanian, this would work as in (21). First, the markedness constraints ${}_N *V[-voice]V$ and ${}_O *V[-voice]V$ are both undominated, forcing all intervocalic obstruents to be voiced. In addition, we assume the markedness constraints ${}_N *VDV$ and ${}_O *VDV$, which ban ‘new’ and ‘old’ intervocalic voiced stops. ${}_N *VDV$ is undominated, so newly derived voiced stops are not allowed intervocalically; as a result, underlying /apa/ becomes [aβa] rather than [aba] (see (21a)). Crucially, ${}_O *VDV$ is ranked below IDENT[cont], so that the ‘old’ intervocalic voiced stop found in underlying /aba/ is protected from spirantisation, as seen in (21b).

²² It is evident from the discussion earlier that Ito & Mester changed their views after writing their 1998 paper, apparently motivated by the need to analyse saltation. We think they were right the first time, and offer an alternative account of saltation below.

One further note on markedness–faithfulness conjunction: Baković (2000) suggests it as a solution to the well-known ‘majority rules’ problem in harmony and assimilation (Lombardi 1999). In light of the argument summarised in this section, we are reluctant to accept his solution, since purely faithfulness-based solutions also exist (e.g. Lombardi’s).

²³ Typically, a markedness violation that is present in the fully faithful candidate will also be present in the underlying form. McCarthy (2003) bases the comparison on the fully faithful candidate rather than the underlying form to avoid potential complications from structures that may not be present underlyingly (e.g. syllable structure).

(21) a. /apa/ → [aβa], not *[aba], due to undominated N^*VDV

/apa/	N^*VDV	$N^*V[-vce]V$	$O^*V[-vce]V$	Id[cont]	O^*VDV	Id[vce]
i. aβa				*		*
ii. apa			*!			
iii. aφα			*!	*		
iv. aba	*!					*

b. /aba/ → [aba], because O^*VDV is ranked below IDENT[cont]

/aba/	N^*VDV	$N^*V[-vce]V$	$O^*V[-vce]V$	Id[cont]	O^*VDV	Id[vce]
i. aβa				*!		
ii. apa		*!				*
iii. aφα		*!		*		*
iv. aba					*	

Comparative markedness has a clear formal connection with the constraint-conjunction approach (see Łubowicz 2003). The crucial similarity is the ability of markedness constraints to assess violations only in cases where a candidate is also unfaithful. In constraint conjunction, this is accomplished by conjoining markedness constraints to faithfulness constraints. In comparative markedness, the same effect is accomplished by allowing N^*M constraints to assess only those markedness violations that are not present in the fully faithful candidate. In each case, markedness constraints are given access to faithfulness, blurring somewhat the traditional distinction between markedness and faithfulness.

Assessing the comparative markedness approach in general terms is a major undertaking, as it has many ramifications (see, notably, McCarthy 2003 and the commentary papers in the same issue of the journal *Theoretical Linguistics*, as well as Hall 2006). Here we point out only that the same kind of ‘phonotactic monsters’ (e.g. voicing contrasts only between obstruents) that were discussed above for the conjoined-constraint approach may also arise in comparative markedness. We demonstrate this with another hypothetical language.

Once again, we assume several garden-variety constraints: (a) two markedness constraints, $O^*[-son, +voice]$ and $N^*[-son, +voice]$, banning ‘old’ and ‘new’ voiced obstruents, (b) two markedness constraints, O^*AGREE and N^*AGREE , which are violated whenever adjacent obstruents disagree in voicing, (c) two markedness constraints, O^*p and N^*p , specifically banning [p] (e.g. as in Arabic and many similar languages with ‘[p]-gaps’ in their stop inventories; see Maddieson 1984: 35), and (d) the faithfulness constraint IDENT[voice]. Consider the ranking of these constraints in (22).

(22) *A phonotactically problematic constraint ranking*

$$O^*p, OAGREE \gg N^*[-son, +voice] \gg N^*p \gg O^*[-son, +voice] \gg NAGREE, IDENT[voice]$$

In this hypothetical language, there is no contrast between voiced and voiceless obstruents in general, as seen in (23). Underlying non-labial voiced stops surface as voiceless because $O^*[-son, +voice] \gg IDENT[voice]$; underlying /b/ and /p/, however, surface as [b] because $O^*p \gg N^*[-son, +voice]$ (i.e. it is better to avoid an old [p] even if doing so requires a new voiced obstruent), and $N^*p \gg O^*[-son, +voice]$ (i.e. it is better to avoid a new [p] even if that means retaining an old voiced obstruent).

(23) a. /ta/ and /da/ → [ta]

	/ta/	O^*p	$OAGREE$	$N^*[-son, +vce]$	N^*p	$O^*[-son, +vce]$	$NAGREE$	$ID[vce]$
☞	i. ta							
	ii. da			*!				*
/da/								
☞	i. ta							*
	ii. da					*!		

b. /pa/ and /ba/ → [ba]

	/pa/	O^*p	$OAGREE$	$N^*[-son, +vce]$	N^*p	$O^*[-son, +vce]$	$NAGREE$	$ID[vce]$
	i. pa	*!						
☞	ii. ba			*				*
/ba/								
	i. pa				*!			*
☞	ii. ba					*		

However, the contrast between /p/ and /b/ is maintained when the sounds are surrounded by two voiceless obstruents, as seen in (24). Moreover, the contrast is maintained by α -switching: /atbka/ surfaces as [atpka], whereas /atpka/ surfaces as [atbka].²⁴

²⁴ We have omitted the four candidates that have only a single AGREE violation ([atpga], [atbga], [adpka], [adbka]), because they do not affect the outcome.

(24) a. /atbka/ → [atpka]

/atbka/	O* _P	O _{AGREE}	N*[-son, +vce]	N* _P	O*[-son +vce]	N _{AGREE}	ID[vce]
i. atpka				*			*
ii. atbka		*!*			*		
iii. adbga			*!*		*		**
iv. adpga		*!*	**	*			***

b. /atpka/ → [atbka]

/atpka/	O* _P	O _{AGREE}	N*[-son, +vce]	N* _P	O*[-son +vce]	N _{AGREE}	ID[vce]
i. atpka	*!						
ii. atbka			*			**	*
iii. adbga			**!*				***
iv. adpga	*!		**			**	**

The reasoning is as follows. Because O_{AGREE} is undominated, the two AGREE violations in underlying /atbka/ in (24a) must be resolved, ruling out candidates [atbka] and [adpga].²⁵ N*[-son, +voice] ≫ N*_P, so the candidate with two new voiced obstruents, [adbga], loses to the candidate with a new [p]. Thus, /atbka/ surfaces as [atpka]. For input /atpka/ in (24b), undominated O*_P rules out candidates [atpka] and [adpga], because the underlying /p/ cannot be maintained. Moreover, N*[-son, +voice] ≫ N_{AGREE}, so [atbka] wins over [adbga]; even though the winner introduces two AGREE violations that were not present underlyingly, this is preferable to introducing three new voiced obstruents. The result is that the underlying contrast between /p/ is /b/ is maintained in this context, flipping the value of the feature [voice].

A look at the factorial typology suggests that this scenario is not an isolated one. We computed the factorial typology of this constraint set using OTSoft 2.3.3 (Hayes *et al.* 2013). Of the 5040 possible rankings of the constraints, there were 45 unique patterns of winners based on the inputs listed above. Of these 45 patterns, five contained a contrast between /p/ and /b/ only in / C _ C contexts.

Again, we judge that the type of phonological behaviour represented in this hypothetical grammar is unlikely to be encountered in any natural language. As with the conjunction of markedness and faithfulness constraints,

²⁵ Assessing violations of O_{AGREE} and N_{AGREE} raises questions about what counts as an ‘old’ violation under the comparative markedness theory. In particular, do the two AGREE violations present in candidate [adpga], given input /atbka/, count as violations of O_{AGREE} or N_{AGREE}? We have assumed that they count as violations of O_{AGREE} even though the voicing of the obstruents has changed between the underlying and surface forms. To be thorough, we also explored grammars in which such cases are considered violations of N_{AGREE}. We found comparable examples of contrast-only-between-obstruents under this interpretation as well.

the fact that such patterns are readily derived with comparative markedness raises questions about whether the potential cost of the theory is too high.²⁶ As with markedness–faithfulness conjunction, it is conceivable the absence of ‘monster’ phonotactic patterns has a purely diachronic explanation, but all else being equal it seems best to have a phonological theory that doesn’t generate them.

Below we present an alternative analysis of saltation that does not make such typological predictions.

6 The analysis of saltation using P-map theory

6.1 Framework: *MAP cum P-map

Zuraw (2007, 2013) proposes to augment the theory of faithfulness beyond the simple constraint types of McCarthy & Prince (1995). In her approach, a constraint of the form *MAP(x, y) assesses a violation to a candidate if a segment belonging to natural class x in the input is mapped to a corresponding segment in natural class y in the output.²⁷ An aspect of Zuraw’s theory that will be essential here is that unlike in classical correspondence theory with IDENT constraints, *MAP constraints can be NON-MINIMAL; specifically, they do not require that the corresponding segments x and y differ in just one feature. Thus, for instance, one could assume a *MAP constraint that penalises input–output pairs like /p/–[β], which differ in both voicing and continuancy.

The theory is thus made more powerful; in compensation, it is constrained in substantive terms. Zuraw suggests that the natural rankings of *MAP constraints are largely determined by phonetics. Specifically, Zuraw adopts from Steriade (2001, 2009) the principle of the P-MAP, or perceptual map, which encodes the perceptual distance between all segment pairs in all contexts. In this approach, *MAP constraints are assigned a default ranking as follows: constraints banning changes that cover a larger perceptual distance are assigned a default ranking higher than constraints banning smaller changes. This ranking preference is taken to be a learning bias in UG; however, given sufficient evidence in the ambient language, it is possible for learners to subvert the default rankings (Zuraw 2007: 297). As we will see (§6.5), this learning bias is crucial in explaining the experimental data on saltation mentioned above in §4.

²⁶ Blumenfeld (2003) suggests a modified version of comparative markedness that does not generate the pathological case described here, and is thus a promising remedy to the problem we have pointed out.

²⁷ Two further details: (i) Zuraw permits *MAP constraints to include contexts – for present purposes, context-free *MAP constraints will suffice; (ii) since the candidates must be assessed for their phonetic properties, it is assumed (Zuraw 2013) that the relevant type of correspondence is output–output (Benua 1997), not input–output as in classical OT; this approach seems feasible for all the cases we have seen.

The basic prediction of the *MAP-cum-P-map proposal – that phonetically salient alternation is disfavoured in comparison to less salient alternation – is supported by a wide variety of evidence. Zuraw uses it to explain the preferred locations for infixes in initial clusters of Tagalog: they occur where the phonetic change induced in the stem is least salient. Similarly, Fleischhacker (2001, 2005) and Shademan (2002) give evidence that in epenthesis alternations it is preferable to place the epenthetic vowel in the location that changes the stem least saliently. Wilson (2006) discusses the direction of generalisation taken by participants in an artificial language study, and suggests that they generalise it to novel cases with less phonetically salient alternation, but not to novel cases where alternation is more salient. Similar experiments, showing that people have difficulty in learning arbitrary phonological alternations that are phonetically extreme, have been carried out by Skoruppa *et al.* (2011) and Stave *et al.* (2013). Lofstedt (2010) shows that paradigm gaps in Swedish vowel-length alternations have arisen in precisely those cases where the distance between long and short vowel pairs is phonetically greatest, owing to concomitant differences of vowel quality. In language acquisition, children are observed to innovate non-adult-like forms that diminish degree of alternation in the paradigm (Hayes 2004, citing Kazazis 1969 and Bernhardt & Stemberger 1998). Lastly, there is evidence that in historical change, phonologies are sometimes restructured by a new generation of learners in ways that reduce the phonetic distance of an alternation (Kiparsky 1982).

6.2 Basics of the proposed analysis

Consider now how the *MAP-cum-P-map approach would be applied to the problem of saltation. The idea is that, given sufficient data to override a learning bias, the system permits rankings that make it possible to analyse saltation. In particular, a *MAP constraint banning correspondence at a greater phonetic distance could be exceptionally ranked below a *MAP constraint banning correspondence at a lesser, subset distance. For Campidanian, the required unnatural ranking is $*\text{MAP}(b, \beta) \gg * \text{MAP}(p, \beta)$.²⁸ Intuitively, this ranking means that it is less bad for voiceless stops to alternate with voiced fricatives than it is for voiced stops to do so, despite the phonetic distances involved. This is what permits /p/ to spirantise but not /b/. The crucial tableaux are given in (25).

²⁸ In our constraint names we use bilabial phonetic symbols as shorthand for natural classes; ‘p’ denotes [–sonorant, –continuant, –voice], ‘b’ denotes [–sonorant, –continuant, +voice] and ‘β’ denotes [–sonorant, +continuant, +voice].

(25) a. /p/ → [β] *intervocally*

/apa/	*MAP(b,β)	*V[-cont]V	*MAP(p,β)	*MAP(p,b)
i. aβa			*	
ii. apa		*!		
iii. aba		*!		*

b. /b/ *is stable*

/apa/	*MAP(b,β)	*V[-cont]V	*MAP(p,β)	*MAP(p,b)
i. aba		*		
ii. aβa	*!			

It is clear from the tableaux that for the analysis to work we must have $*MAP(b, \beta) \gg *V[-cont]V$ (to block spirantisation of /b/) and also $*V[-cont]V \gg *MAP(p, \beta)$ (so that /p/ will spirantise). By transitivity, this yields $*MAP(b, \beta) \gg *MAP(p, \beta)$, in violation of the P-map. Thus, although Campidanian is a possible phonology, it is claimed to be harder for language learners, since it requires a ranking that is not P-map-compliant.

6.3 The complete analysis

To make sure our analysis works, we carried it out again, with additional candidates and constraints. In addition to the core cases /apa/ → [aβa] and /aba/ → [aba], we must make sure that (a) /p/ and /b/ are stable when not intervocalic: /pa/ → [pa], /ba/ → [ba], and (b) [β] does not surface except when derived by spirantisation from /p/. For the latter, we follow the principle of the rich base (Prince & Smolensky 1993: §9.3), requiring that illegal forms surface as something legal. In particular, hypothetical /βa/ must surface as some legal form, which (as it turns out) our analysis predicts to be [pa], and /aβa/ must likewise surface as something legal, which (as it turns out) our analysis predicts to be [aβa].

As candidates we included all three possible output consonants ([p b β]) for all of our input forms, which cover all three consonants in both initial and intervocalic environments. We also assumed for present purposes that the $*MAP$ constraints are symmetrical, so that /pa/ → [ba] and /ba/ → [pa] are equally penalised by $*MAP(p, b)$.

We executed the analysis using OTSoft 2.3.3 (Hayes *et al.* 2013), which ranked the constraints using Recursive Constraint Demotion (Tesar & Smolensky 1995), suitably constrained to respect the *a priori* ranking $*MAP(p, \beta) \gg *MAP(p, b)$.²⁹ The resulting tableaux are given in (26).

²⁹ As Norval Smith has pointed out to us, the analysis will work even if $*MAP(p, \beta)$ is removed; we include it under the assumption that when children encounter a real alternation in a language they set up a $*MAP$ constraint to cover it.

(26) a. *Lenition of intervocalic /p/*

/apa/	*V[-vce]V	*M _{AP} (b,β)	*V[-cont]V	*β	*M _{AP} (p,β)	*M _{AP} (p,b)	*b
i. aβa				*	*		
ii. apa	*!		*				
iii. aba			*!			*	*

b. *Intervocalic /b/ is stable*

/aba/	*V[-vce]V	*M _{AP} (b,β)	*V[-cont]V	*β	*M _{AP} (p,β)	*M _{AP} (p,b)	*b
i. aβa		*!		*			
ii. apa	*!		*			*	
iii. aba			*				*

c. *Initial /p/ is stable*

/pa/	*V[-vce]V	*M _{AP} (b,β)	*V[-cont]V	*β	*M _{AP} (p,β)	*M _{AP} (p,b)	*b
i. pa							
ii. ba						*!	*
iii. βa				*!	*		

d. *Initial /b/ is stable*

/ba/	*V[-vce]V	*M _{AP} (b,β)	*V[-cont]V	*β	*M _{AP} (p,β)	*M _{AP} (p,b)	*b
i. pa						*!	
ii. ba							*
iii. βa		*!		*			

e. *Rich base ‘/β/’ indistinguishable from /p/ when initial*

/βa/	*V[-vce]V	*M _{AP} (b,β)	*V[-cont]V	*β	*M _{AP} (p,β)	*M _{AP} (p,b)	*b
i. pa					*		
ii. ba		*!					*
iii. βa				*!			

f. *Rich base ‘/β/’ indistinguishable from /p/ when intervocalic*

/aβa/	*V[-vce]V	*M _{AP} (b,β)	*V[-cont]V	*β	*M _{AP} (p,β)	*M _{AP} (p,b)	*b
i. aβa				*			
ii. aba		*!	*				*
iii. apa	*!		*		*		

For the sake of rigour we determined the ranking argumentation not by hand, but by using the Fusional Reduction Algorithm of Brasoveanu & Prince (2011), as implemented in OTSoft. Applied to the winner–loser pairs contained in the tableaux, the Fusional Reduction Algorithm yielded a simple pattern consisting of one strictly ranked chain of length six, plus one unranked constraint.

(27) a. *Ranking*

*MAP(b, β) ≫ *V[–cont]V ≫ *β ≫ *MAP(p, β) ≫ *MAP(p, b) ≫ *b

b. *No ranking required*

*V[–voice]V

Intuitively, the ranking arguments are as follows. *MAP(b, β) must dominate *V[–cont]V in order to avoid spirantisation of /aba/ in (26b). *V[–cont]V must dominate *β, because although [β] is generally avoided in the language, it is tolerated in order to avoid a spirantisation violation, as in (26a). *β must dominate *MAP(p, β) (equivalent to *MAP(β, p), under our assumption of symmetry), because in our analysis the rich-base input /βa/ surfaces as [pa] ((26e)). *MAP(p, β) must dominate *MAP(p, b) under the theoretical assumption that language learners adopt P-map-compliant rankings whenever evidence to the contrary is not present. *MAP(p, b) dominates *b, the normal ranking in languages such as Campidanian, where voicing in obstruents is phonemic; see (26d). The constraint *V[–voice]V, though it *can* be placed top of the rankings (it is unviolated in winners), could actually be ranked anywhere at all; indeed, for the data given, the analysis works when *V[–voice]V is removed from the constraint set.³⁰

The analysis succeeds in ruling out any unattested patterns of alternation. If any forms are assigned underlying /β/, they will surface with [β] intervocally and [p] elsewhere – i.e. exactly like underlying /p/. If Campidanian learners capriciously chose an underlying form with /β/, it would be undetectable in their speech, which is what we want. Appropriate rankings of the *MAP constraints involving voiceless fricatives would likewise render any underlying /ϕ/ harmless.

For other cases of saltation, similar analyses can easily be constructed. The common theme is the non-default ranking of a *MAP constraint that bans a long ‘phonetic path’ of alternation below a *MAP constraint that bans a subset of this path.

6.4 A second saltation in Campidanian

For completeness, we mention that Campidanian possesses a second saltatory alternation. The voiced geminate stops [b: d: g:], which are themselves normally derived from underlying clusters, are in a state of free variation: sometimes they are realised as such, but more often they are lenited to

³⁰ It is needed in the phonology as a whole to account for cases like /asa/ → [aza] (Bolognesi 1998: 149).

[β ð γ], thus merging with underlying /p t k/ (Bolognesi 1998: 48). Since (as before) singleton [b d g] do not lenite, this is another saltation: [b:] – [b] – [β]. The diachronic origin of this saltation is the same as before; namely the restoration of [b] in intervocalic position by grammar change.³¹

We have found that it is not hard to model this saltation with the same basic devices used above; the essential aspect of the analysis is a non-P-map compliant ranking, $*\text{MAP}(b, \beta) \gg * \text{MAP}(b, \beta)$. Full tableaux and Hasse diagrams can be found in the online supplementary materials.

As a reviewer points out, our $*\text{MAP}$ approach makes predictions across phonological processes: the aberrantly high ranking of $*\text{MAP}(b, \beta)$ is the cause of both Campidanian saltations. Such predictions are not made by theoretical alternatives such as ‘crazy rules’ (in rule-based phonology) or ‘anticorrespondence’ constraints (Hayes 1999).

6.5 Accounting for experimental results on learning bias with computational modelling

We briefly discuss here how the analysis we have presented can be adapted to explain the experimental results described above (§4). Recall that when experimental participants are exposed to alternations like [p] ~ [v], they tend to generalise the pattern to [b] ~ [v], despite the presence of non-alternating [b] in the training data. We show how this can be accounted for using the P-map framework assumed above; the discussion below briefly summarises White (2013: ch. 4).

In order to model the P-map-based learning bias, White shifts from the classical OT model used above to the closely related framework of maximum entropy grammar (Goldwater & Johnson 2003). White employs essentially the constraints assumed above in our Campidanian analysis, namely $*V[-\text{voice}]V$, $*V[-\text{cont}]V$ and all relevant $*\text{MAP}$ constraints. As a first step, he establishes a phonetically realistic and quantitatively explicit P-map, using confusion matrices from earlier perception experiments. The P-map is then used as the basis for establishing Gaussian priors (i.e. preferred values) on the weights of the $*\text{MAP}$ constraints. As a result, the learning model has an *a priori* expectation that $*\text{MAP}$ constraints will be weighted more highly if they penalise correspondences spanning large phonetic distances. In implementing the P-map bias by way of the prior, White follows the general approach pioneered by Wilson (2006), though White’s implementation differs in various ways.

³¹ Smith *et al.* (1991: 326) suggest that geminate lenition is determined by stress, but note ‘exceptions ... which we cannot explain’; our own impression is that such exceptions are fairly numerous. The hypothesis of free variation is supported by Bolognesi (1998: 497), where the underlying sequence /pɔtiat bi/ ‘can see’ is realised in the same discourse first as [poðia βiri], then as [poðia biiri] (the [ri] syllable is epenthetic (1998: 448)).

Smith *et al.* also take the view that Campidanian ‘geminate’ are not actually long phonetically. Bolognesi (1998) is uncertain on this point, though he does transcribe surface distinctions between [b] and [b:], for example. Plainly, phonetic study would be useful.

The model was used to conduct a learning simulation of the artificial language experiments described above in §4. The training data for the model were identical to the set of forms that the participants received in the experiments. When the learned grammar was tested on the same data used for the test items with human participants, it achieved a close approximation of human performance. In particular, when trained on alternations like [p] ~ [v], the model also generalised to [b] ~ [v], even when cases of non-alternating [b] were presented during training.

If these experimental and modelling results can be extrapolated to real languages, then they offer the possibility of explaining the cases of historical change (§4) in which saltatory systems broke down, the idea being that this occurred because saltation was difficult for new generations of language learners to acquire. Going further, if, as we suspect, saltatory alternations are rare, learning bias could be taken as a contributing explanation for their rarity. This idea must be regarded as quite speculative, for three reasons: we don't know for sure whether saltation is rare, we have only given limited evidence that it is unstable, and the rarity of saltation is already expected on diachronic grounds if, as we argued (§3), it cannot be produced by sound change. Thus saltation is a classic instance of Moreton's dilemma (2008): it is very often the case that we cannot confidently attribute a typological pattern to channel bias (i.e. diachronic explanation) or analytic bias (the factor demonstrated in White's experiments). In sum, we think far more evidence must be gathered if we are to make any sort of confident assertion that White's results bear on phonological typology.

6.6 Can the P-map approach overgenerate?

In §5.2, we argued that the conjoined constraint approach – specifically, the conjunction of markedness and faithfulness constraints – should be avoided in phonological theory due to the bad typological predictions about phonotactics that arise when such conjunctions are allowed. In §5.3 we suggested that similar bad predictions emerge from the theory of comparative markedness, though as yet we have no systematic understanding of the basis from which they arise. The *MAP approach that we propose here also allows marked patterns to arise in synchronic phonology; indeed, saltation, as we have argued, is one of them. However, we hold that the *MAP-cum-P-map approach is more principled in the types of marked patterns that it allows.

Let us return to our earlier example, in which theories wrongly predict the existence of languages that contrast /p/ and /b/ only when flanked by obstruents; as we showed, both constraint conjunction and comparative markedness can derive this pattern. Moreover, the relevant analyses employ only garden-variety phonological constraints. In the constraint-conjunction theory, it was sufficient to conjoin IDENT[voice] with a constraint banning consonant clusters. For comparative markedness, the relevant constraints were 'old' and 'new' versions of AGREE[voice],

*[-son, +voice] and *p, all of which have strong typological support. Therefore, the problems seem to reside in the core mechanisms used in these theories, rather than in the particular constraints being employed.

Could the *MAP-cum-P-map approach generate comparable phonotactic ‘monsters’? We judge that, suitably constrained, it will not. There are two circumstances under which the approach could generate a monster. First, and trivially, CON could include constraints that ban configurations that we recognise as phonotactically good rather than bad. An example would be a ban on non-branching onsets, so that /pa/ surfaces (say) as [pra]. This bad possibility is shared by all theories, and it seems reasonable for any theory to assume a CON component that does not include such pathological markedness constraints.

The special properties of the *MAP-cum-P-map approach reside not in its markedness constraints, but in its faithfulness constraints, and especially in the possibility of their being ranked in ways that go against the P-map. Monsters could arise if a *MAP constraint somehow permitted a repair to occur only in a marked context, as with, say *MAP(p, b) / [-son]__[-son], forbidding changes in voicing for /p/ or /b/ flanked by obstruents. With a constraint of this sort, we could derive a pattern where obstruents contrast in voicing only when flanked by other obstruents by ranking the *MAP constraints in the anti-P-map fashion: *MAP(p, b) / [-son]__[-son] \gg *p \gg *MAP(p, b) / #__V. This would permit /atpka/ and /atbka/ to surface faithfully, but would force /pa/ to be repaired as [ba], neutralising it with /ba/ and creating a monster similar to what we saw in §5.3.

The monster will arise only if we permit the theory to include faithfulness constraints that militate against alternation in marked contexts, such as [-son]__[-son]. The appropriateness of contextually limited faithfulness itself has been questioned (Prince & Tesar 2004: 277–278), but those contextually limited faithfulness constraints that have been proposed tend to invoke *unmarked* contexts; for instance, Beckman (1998) proposes onset faithfulness, root-initial faithfulness and stressed-syllable faithfulness, all plausibly unmarked. Thus, assuming that we specify that phonological theory must forbid faithfulness constraints that specifically invoke marked contexts, we think that the phonotactic overgeneration problem that faces constraint conjunction and comparative markedness does not face the P-map approach.

Turning from phonotactics to alternations: it is unquestionably the case that the *MAP-cum-P-map approach can generate pathological alternation types – but we think that these exist, and saltation is just one of them. We think it an advantage of the *MAP-cum-P-map approach that it comes with a more principled way of determining *how* marked one pattern is relative to another, namely a substantive bias based on the P-map.

7 How does grammar change create saltation?

We turn finally to a problem about which we can only speculate. As we argued in §3.2, the saltatory pattern of Campidanian was itself created by grammar change; specifically, the voiced stop $\sim \emptyset$ alternations were largely levelled in favour of non-alternating voiced stops. But how did grammar change achieve a configuration that we have just characterised as a marked one? We speculate as follows. First, some principle of neutralisation avoidance may have been at play (e.g. following Flemming 1995, 2004, Bolognesi 1998: ch. 5 and Padgett 2003, 2009): the reversion of voiced stops keeps the three places of articulation [b d g] from neutralising with each other, and is ‘better’ than reverting to [β ð γ], which would have involved neutralisation with underlying /p t k/. Second, there is the possibility that grammar change is sometimes ‘locally improving’, in the sense laid out by Kiparsky (1978): the complete reversion of the voiced stop $\sim \emptyset$ constituted a huge local improvement with respect to the P-map for these alternations considered alone, though it created a disfavoured ranking of the *MAP constraints in the grammar as a whole, creating a less favoured grammar at the global level. We consider it a challenge for future work in modelling phonological learning and grammar change to provide formal models that can account for the Campidanian change, as well as the changes that appear to be levelling out saltation in Russian and Manga Kanuri.

8 Conclusion

We offer conclusions in three areas.

Concerning the role of biases in phonological learning, we think the evidence we have examined points to a moderate stance, ruling out two extremes. If the P-map bias we posit did not exist, then we could not explain the experimental results described in §4. But if the bias were extreme, saltatory alternations would not exist at all.

Concerning diachrony, our exploration of the origins of saltation supports the view of Minkova (1993) and Lass (1997) that it never arises from sound change but comes from factors like telescoping or restructuring; it is a classic case of ‘unnatural’ phonology.

Concerning restrictiveness in phonological theory, we argued that a learning-bias approach using Zuraw’s *MAP cum P-map is more promising than conjoined constraints or comparative markedness: *MAP cum P-map is not only supported as a learning bias by experimental data, but also avoids the problems faced by earlier accounts of generating implausible phonotactic patterns.

REFERENCES

- Anderson, Stephen R. (1981). Why phonology isn't 'natural'. *LI* 12. 493–539.
- Anderson, Stephen R. (1985). *Phonology in the twentieth century: theories of rules and theories of representations*. Chicago: University of Chicago Press.
- Anderson, Stephen R. & Wayles Browne (1973). On keeping exchange rules in Czech. *Papers in Linguistics* 6. 445–482.
- Anttila, Arto (2012). Modeling phonological variation. In Abigail C. Cohn, Cécile Fougeron & Marie K. Huffman (eds.) *The Oxford handbook of laboratory phonology*. Oxford: Oxford University Press. 76–91.
- Aronoff, Mark, Azhar Arsyad, Hasan Basri & Ellen Broselow (1987). Tier configuration in Makassarese reduplication. *CLS* 23:2. 1–15.
- Bach, Emmon & Robert T. Harms (1972). How do languages get crazy rules? In Robert P. Stockwell & Ronald K. S. Macaulay (eds.) *Linguistic change and generative theory*. Bloomington: Indiana University Press. 1–21.
- Baković, Eric (2000). *Harmony, dominance, and control*. PhD dissertation, Rutgers University.
- Becker, Michael, Andrew Nevins & Jonathan Levine (2012). Asymmetries in generalizing alternations to and from initial syllables. *Lg* 88. 231–268.
- Beckman, Jill N. (1997). Positional faithfulness, positional neutralisation and Shona vowel harmony. *Phonology* 14. 1–46.
- Beckman, Jill N. (1998). *Positional faithfulness*. PhD dissertation, University of Massachusetts, Amherst.
- Benua, Laura (1997). *Transderivational identity: phonological relations between words*. PhD dissertation, University of Massachusetts, Amherst.
- Bernhardt, Barbara H. & Joseph P. Stemberger (1998). *Handbook of phonological development from the perspective of constraint-based nonlinear phonology*. San Diego: Academic Press.
- Blevins, Juliette (2004). *Evolutionary Phonology: the emergence of sound patterns*. Cambridge: Cambridge University Press.
- Blumenfeld, Lev (2003). Counterfeeding, derived environment effects, and comparative markedness. *Theoretical Linguistics* 29. 89–99.
- Bolognesi, Roberto (1998). *The phonology of Campidanian Sardinian: a unitary account of a self-organizing structure*. PhD dissertation, University of Amsterdam.
- Bowers, Dustin (2012). *Phonological restructuring in Odawa*. MA thesis, University of California, Los Angeles. Available (May 2015) at <https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnxkdXN0aW5ib3dldnNsaW5ndWlzdHxneDo2ZTI5N2JhZjQ2MzM3Y2Fm>.
- Bradshaw, Mary M. (1995). Tone on verbs in Suma. In Akinbiyi Akinlabi (ed.) *Theoretical approaches to African linguistics*. Trenton, NJ: Africa World Press. 255–271.
- Bradshaw, Mary M. (1998). Tone alternations in the associative construction of Suma. In Ian Maddieson & Thomas J. Hinnebusch (eds.) *Language history and linguistic description in Africa*. Trenton, NJ: Africa World Press. 117–125.
- Bradshaw, Mary M. (1999). Unrecoverable origins. In Hermans & van Oostendorp (1999). 51–80.
- Brasoveanu, Adrian & Alan Prince (2011). Ranking and necessity: the Fusional Reduction Algorithm. *NLLT* 29. 3–70.
- Buckley, Eugene (2000). On the naturalness of unnatural rules. *UCSB Working Papers in Linguistics* 9. 16–29.
- Bybee, Joan (1985). *Morphology: a study of the relation between meaning and form*. Amsterdam & Philadelphia: Benjamins.
- Bynon, Theodora (1977). *Historical linguistics*. Cambridge: Cambridge University Press.

- Casali, Roderic F. (1997). Vowel elision in hiatus contexts: which vowel goes? *Lg* 73. 493–533.
- Crosswhite, Katherine M. (2000). Vowel reduction in Russian: a unified account of standard, dialectal, and ‘dissimilative’ patterns. *University of Rochester Working Papers in the Language Sciences* 1. 107–172.
- Crowhurst, Megan J. (2011). Constraint conjunction. In Marc van Oostendorp, Colin J. Ewen, Elizabeth Hume & Keren Rice (eds.) *The Blackwell companion to phonology*. Malden, Mass.: Wiley-Blackwell. 1461–1490.
- Crowhurst, Megan J. & Mark Hewitt (1997). *Boolean operations and constraint interactions in Optimality Theory*. Ms, University of North Carolina at Chapel Hill & Brandeis University. Available as ROA-229 from the Rutgers Optimality Archive.
- Dobson, E. J. (1968). *English pronunciation 1500–1700*. 2nd edn. Vol. 2: *Phonology*. Oxford: Clarendon.
- Downing, Laura J. (1998). On the prosodic misalignment of onsetless syllables. *NLLT* 16. 1–52.
- Fleischhacker, Heidi (2001). Cluster-dependent epenthesis asymmetries. *UCLA Working Papers in Linguistics* 7: *Papers in Phonology* 5. 71–116.
- Fleischhacker, Heidi (2005). *Similarity in phonology: evidence from reduplication and loan adaptation*. PhD dissertation, University of California, Los Angeles.
- Flemming, Edward (1995). *Auditory representations in phonology*. PhD dissertation, University of California, Los Angeles.
- Flemming, Edward (2004). Contrast and perceptual distinctiveness. In Bruce Hayes, Robert Kirchner & Donca Steriade (eds.) *Phonetically based phonology*. Cambridge: Cambridge University Press. 232–276.
- Goldwater, Sharon & Mark Johnson (2003). Learning OT constraint rankings using a Maximum Entropy model. In Jennifer Spenador, Anders Eriksson & Östen Dahl (eds.) *Proceedings of the Stockholm Workshop on Variation within Optimality Theory*. Stockholm: Stockholm University. 111–120.
- Hall, T. A. (2006). Derived Environment Blocking effects in Optimality Theory. *NLLT* 24. 803–856.
- Hayes, Bruce (1995). *Metrical stress theory: principles and case studies*. Chicago: University of Chicago Press.
- Hayes, Bruce (1999). Phonological restructuring in Yidiñ and its theoretical consequences. In Hermans & van Oostendorp (1999). 175–205.
- Hayes, Bruce (2004). Phonological acquisition in Optimality Theory: the early stages. In Kager *et al.* (2004). 158–203.
- Hayes, Bruce, Bruce Tesar & Kie Zuraw (2013). *OTSoft 2.3.3*. Software package. <http://www.linguistics.ucla.edu/people/hayes/otsoft/>.
- Hermans, Ben & Marc van Oostendorp (eds.) (1999). *The derivational residue in phonological Optimality Theory*. Amsterdam & Philadelphia: Benjamins.
- Hutchison, John P. (1981). *A reference grammar of the Kanuri language*. Madison: African Studies Program, University of Wisconsin.
- Hyman, Larry M. (1975). *Phonology: theory and analysis*. New York: Holt, Rinehart & Winston.
- Inkelas, Sharon (1999). Exceptional stress-attracting suffixes in Turkish: representations versus the grammar. In René Kager, Harry van der Hulst & Wim Zonneveld (eds.) *The prosody–morphology interface*. Cambridge: Cambridge University Press. 134–187.
- Itô, Junko & Armin Mester (1997). Correspondence and compositionality: the ga-gyō variation in Japanese phonology. In Iggy Roca (ed.) *Derivations and constraints in phonology*. Oxford: Clarendon. 419–462.
- Ito, Junko & Armin Mester (1998). *Markedness and word structure: OCP effects in Japanese*. Ms, University of California, Santa Cruz. Available as ROA-255 from the Rutgers Optimality Archive.

- Ito, Junko & Armin Mester (2003). On the sources of opacity in OT: coda processes in German. In Caroline Féry & Ruben van de Vijver (eds.) *The syllable in Optimality Theory*. Cambridge: Cambridge University Press. 271–303.
- Jarrett, Kevin (2007). *A dictionary of Manga, a Kamuri language of Eastern Niger and NE Nigeria*. Revised and edited by Roger Blench. Available (May 2015) at <http://www.rogerblench.info/Language/Nilo-Saharan/Saharan/MangadictionaryUnicode.pdf>.
- Kager, René, Joe Pater & Wim Zonneveld (eds.) (2004). *Constraints in phonological acquisition*. Cambridge: Cambridge University Press.
- Kaye, Jonathan (1978). Rule mitosis: the historical development of Algonquian palatalization. In Eung-Do Cook & Jonathan Kaye (eds.) *Linguistic studies of native Canada*. Vancouver: University of British Columbia Press. 143–156.
- Kazazis, Kostas (1969). Possible evidence for (near-)underlying forms in the speech of one child. *CLS* 5. 382–388.
- Kenstowicz, Michael & Charles Kisseberth (1977). *Topics in phonological theory*. New York: Academic Press.
- King, Robert D. (1969). *Historical linguistics and generative grammar*. Englewood Cliffs, NJ: Prentice-Hall.
- Kiparsky, Paul (1965). *Phonological change*. PhD dissertation, MIT. Available (May 2015) at <http://dspace.mit.edu/handle/1721.1/13011>.
- Kiparsky, Paul (1968). Linguistic universals and linguistic change. In Emmon Bach & Robert T. Harms (eds.) *Universals in linguistic theory*. New York: Holt, Rinehart & Winston. 170–202.
- Kiparsky, Paul (1973). Abstractness, opacity, and global rules. In Osamu Fujimura (ed.) *Three dimensions in linguistic theory*. Tokyo: TEC. 57–86.
- Kiparsky, Paul (1978). Analogical change as a problem for linguistic theory. *Studies in the Linguistic Sciences* 8:2. 77–96.
- Kiparsky, Paul (1982). *Explanation in phonology*. Dordrecht: Foris.
- Labov, William (1994). *Principles of linguistic change*. Vol. 1: *Internal factors*. Oxford & Cambridge, Mass.: Blackwell.
- Ladd, D. Robert & James M. Scobbie (2003). External sandhi as gestural overlap? Counter-evidence from Sardinian. In John Local, Richard Ogden & Rosalind Temple (eds.) *Phonetic interpretation: papers in laboratory phonology VI*. Cambridge: Cambridge University Press. 164–182.
- Lass, Roger (1997). *Historical linguistics and language change*. Cambridge: Cambridge University Press.
- Lofstedt, Ingvar (2010). *Phonetic effects in Swedish phonology: allomorphy and paradigms*. PhD dissertation, University of California, Los Angeles.
- Lombardi, Linda (1999). Positional faithfulness and voicing assimilation in Optimality Theory. *NLLT* 17. 267–302.
- Łubowicz, Anna (2002). Derived environment effects in Optimality Theory. *Lingua* 112. 243–280.
- Łubowicz, Anna (2003). Local conjunction and comparative markedness. *Theoretical Linguistics* 29. 101–112.
- McCarthy, John J. (2003). Comparative markedness. *Theoretical Linguistics* 29. 1–51.
- McCarthy, John J. (ed.) (2004). *Optimality Theory in phonology: a reader*. Malden, Mass. & Oxford: Blackwell.
- McCarthy, John J. & Alan Prince (1995). Faithfulness and reduplicative identity. In Jill N. Beckman, Laura Walsh Dickey & Suzanne Urbanczyk (eds.) *Papers in Optimality Theory*. Amherst: GLSA. 249–384.
- Maddieson, Ian (1984). *Patterns of sounds*. Cambridge: Cambridge University Press.
- Mascaró, Joan (1996). External allomorphy as emergence of the unmarked. In Jacques Durand & Bernard Laks (eds.) *Current trends in phonology: models and methods*.

- Salford: ESRI. 473–483. Reprinted 2004 in John J. McCarthy (ed.) *Optimality Theory in phonology*. Oxford: Blackwell. 513–522.
- Minkova, Donka (1993). On leapfrogging in historical phonology. In Jaap van Marle (ed.) *Historical linguistics 1991: papers from the 10th International Conference on Historical Linguistics, Amsterdam, August 12–16, 1991*. Amsterdam: Benjamins. 211–228.
- Mohanan, K. P. (1982). *Lexical Phonology*. PhD dissertation, MIT. Distributed by Indiana University Linguistics Club.
- Moreton, Elliott (2008). Analytic bias and phonological typology. *Phonology* 25. 83–127.
- Padgett, Jaye (2003). Contrast and post-velar fronting in Russian. *NLLT* 21. 39–87.
- Padgett, Jaye (2009). Systemic contrast and Catalan rhotics. *The Linguistic Review* 26. 431–463.
- Pilch, Herbert (1966). Das Lautsystem der hochdeutschen Umgangssprache. *Zeitschrift für Mundartforschung* 33. 247–266.
- Prince, Alan & Paul Smolensky (1993). *Optimality Theory: constraint interaction in generative grammar*. Ms, Rutgers University & University of Colorado, Boulder. Published 2004, Malden, Mass. & Oxford: Blackwell.
- Prince, Alan & Bruce Tesar (2004). Learning phonotactic distributions. In Kager *et al.* (2004). 245–291.
- Robinson, Orrin W. (2001). *Whose German? The ach/ich alternation and related phenomena in 'standard' and 'colloquial'*. Amsterdam & Philadelphia: Benjamins.
- Rubach, Jerzy (1984). *Cyclic and Lexical Phonology: the structure of Polish*. Dordrecht: Foris.
- Rubach, Jerzy (1993). *The lexical phonology of Slovak*. Oxford: Clarendon.
- Salmons, Joseph (2012). *A history of German: what the past reveals about today's language*. Oxford: Oxford University Press.
- Schirmunski, V. M. (1962). *Deutsche Mundartkunde: vergleichende Laut- und Formenlehre der deutschen Mundarten*. Berlin: Akademie-Verlag.
- Schuh, Russell G. (2003). The linguistic influence of Kanuri on Bade and Ngizim. *Maiduguri Journal of Linguistic and Literary Studies (MAJOLLS)* 5. 55–89.
- Schuh, Russell G. (2005). The history of labial and velar obstruents in Kanuri. Ms, University of California, Los Angeles.
- Shademan, Shabnam (2002). *Epenthetic vowel harmony in Farsi*. MA thesis, University of California, Los Angeles.
- Skoruppa, Katrin, Anna Lambrechts & Sharon Peperkamp (2011). The role of phonetic distance in the acquisition of phonological alternations. *NELS* 39:2. 717–729.
- Smith, Norval, Mieke Beers, Rens Bod, Roberto Bolognesi, Helga Humbert & Frank van der Leeuw (1991). Lenition in a Sardinian dialect. In Pier Marco Bertinetto, Michael Kenstowicz & Michele Loporcaro (eds.) *Certamen phonologicum II: papers from the 1990 Cortona Phonology Meeting*. Turin: Rosenberg & Sellier. 309–328.
- Smith, Norval & Vinije Haabo (2007). The Saramaccan implosives: tools for linguistic archaeology? *Journal of Pidgin and Creole Languages* 22. 101–122.
- Smolensky, Paul (1995). On the internal structure of the constraint component *Con* of UG. Ms, Johns Hopkins University. Available as ROA-86 from the Rutgers Optimality Archive.
- Stampe, David (1973). *A dissertation on Natural Phonology*. PhD dissertation, University of Chicago.
- Stave, Matthew, Amy Smolek & Vsevolod Kapatsinski (2013). Inductive bias against stem changes as perseveration: experimental evidence for an articulatory approach to Output-Output Faithfulness. *Proceedings of the 35th Annual Meeting of the Cognitive Science Society*. Austin: Cognitive Science Society. 3454–3459.

- Steriade, Donca (2001). Directional asymmetries in place assimilation: a perceptual account. In Elizabeth Hume & Keith Johnson (eds.) *The role of speech perception in phonology*. San Diego: Academic Press. 219–250.
- Steriade, Donca (2009). The phonology of perceptibility effects: the P-map and its consequences for constraint organization. In Kristin Hanson & Sharon Inkelas (eds.) *The nature of the word: studies in honor of Paul Kiparsky*. Cambridge, Mass.: MIT Press. 151–179.
- Sundara, Megha, Yun Jung Kim, James White & Adam J. Chong (2013). There is no *pat* in *patting*: acquisition of phonological alternations by English-learning 12-month-olds. Paper presented at the 38th Boston University Conference on Language Development. Available (May 2015) at http://www.ucl.ac.uk/~ucjtcwh/index_files/SundaraEtAl_BUCLD2013.pdf.
- Tesar, Bruce & Paul Smolensky (1995). The learnability of Optimality Theory. *WCCFL* 13. 122–137.
- Vaux, Bert (2002). Consonant epenthesis and the problem of unnatural phonology. Ms, Harvard University.
- Vennemann, Theo (1972a). Rule inversion. *Lingua* 29. 209–242.
- Vennemann, Theo (1972b). Phonetic analogy and conceptual analogy. In Theo Vennemann & Terence H. Wilbur (eds.) *Schuchardt, the Neogrammarians, and the transformational theory of phonological change*. Frankfurt am Main: Athenäum. 181–204.
- Viridis, Maurizio (1978). *Fonetica storica del dialetto Campidanese*. Cagliari: Edizioni della Torre.
- White, James (2013). *Bias in phonological learning: evidence from saltation*. PhD dissertation, University of California, Los Angeles.
- White, James (2014). Evidence for a learning bias against saltatory phonological alternations. *Cognition* 130. 96–115.
- White, James & Megha Sundara (2014). Biased generalization of newly learned phonological alternations by 12-month-old infants. *Cognition* 133. 85–90.
- Wilson, Colin (2006). Learning phonology with substantive bias: an experimental and computational study of velar palatalization. *Cognitive Science* 30. 945–982.
- Zuraw, Kie (2007). The role of phonetic knowledge in phonological patterning: corpus and survey evidence from Tagalog infixation. *Lg* 83. 277–316.
- Zuraw, Kie (2013). *MAP constraints. Ms, University of California, Los Angeles. Available (May 2015) at www.linguistics.ucla.edu/people/zuraw/dnldpprs/star_map.pdf.