Phonetics in Phonology: Evidence from Scottish Gaelic Preaspiration[*]

Ian Clayton

University of North Carolina, Chapel Hill

1. Introduction

Some phonological patterns are crosslinguistically commonplace, while others are comparatively rare. For instance, many languages license only voiceless obstruents in syllable codas, while permitting both voiced and voiceless obstruents in syllable onsets. Languages with the opposite pattern, synchronically voicing underlying voiceless coda obstruents, are at best rare (Blevins 2004, Kiparsky 2006). Nasal + voiceless obstruent sequences are also prohibited in many languages; attested repairs include voicing the obstruent, deleting the nasal, deleting the obstruent, or replacing the nasal with its oral counterpart, but exclude metathesis and epenthesis, though both of these strategies would also eliminate the offending cluster (Pater 1996, Myers 2002). Finally, consider preaspirated voiceless stops: such stops are attested in at best two dozen languages worldwide, while postaspirated voiceless stops are widespread, and unaspirated voiceless stops are well-nigh universal (Silverman 2003, Ladefoged and Maddieson 1996, Maddieson 1984).

Vigorously debated are the reasons behind such typological gaps or asymmetries. Two schools of thought have emerged. On the one hand are those proposals which attribute typology to UG, or to cognitive biases generally; such innate predispositions have been collectively referred to as *analytic bias* (Moreton 2008a, Wilson 2003). A prominent example is the P-map hypothesis (Steriade 2001a, 2001b). According to this hypothesis, the P-map is a component of the phonological grammar, through which the projection and ranking of faithfulness constraints are based on scales of perceptual similarity. Thus, /tæb/ » [tæp] (devoicing) is an attested repair to *[+VOICE]/_]word, but [tæm] (nasalization), [tæw] (gliding), or [bæt] (metathesis) are not, precisely because they are perceptually farther removed from the target than devoicing (Steriade 2001a).

---

[*] Grateful acknowledgment is made to Jen Smith, Melissa Frazier, and especially Elliott Moreton for their invaluable advice and suggestions during this study. Errors are my own.

On the other hand are those who grant little or no role to such innate constraints, arguing instead that phonological typology is principally a product of *channel bias* (term after Moreton 2008b); that is, selective physical forces acting upon the articulation and perception of the speech signal, weeding out those patterns which are most prone to misapprehension or failure of transmission (Ohala 2005, Blevins 2004, Silverman 2003); alternatively, that certain patterns seldom or never are phonologized because the necessary precursors are absent (Myers 2002). According to this view, a word-final environment is a prime locus for the phonetic neutralization of VOT contrasts, which then becomes phonologized. Conversely, [tæm], [tæw], and [bæt] are unattested realizations of /tæp/ because there are no corresponding phonetic priors.

This paper provides new support for the Channel Bias hypothesis, drawing evidence from two asymmetries in the typology of Scottish Gaelic preaspirated voiceless stops. The paper proceeds as follows. The asymmetries within Scottish Gaelic preaspiration are illustrated in §2. In §3, I show that a standard OT analysis of these asymmetries results in significant overgeneration, and that modifying the original OT analysis via the P-map resolves the overgeneration. Problematically, however, this analysis is provisional, since it depends on as-yet undemonstrated perceptual scales. §4 describes a production experiment which identifies robust phonetic precursors for both asymmetries. §5 discusses the study's findings and implications. Finally, the paper is summarized in §6.

2. Preaspiration in Scottish Gaelic: two asymmetries

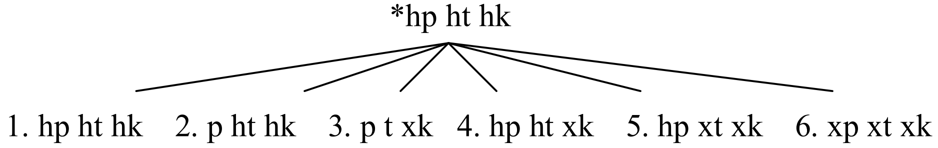
In most dialects of Scottish Gaelic (SG), there are two phonemic stop series, distinguished by aspiration: voiceless nonaspirated /p t̪ t̪^{j} k^{j} k/< > voiceless aspirated /p t̪ t̪^{hj} k^{hj} k/[1] (Lamb 2001). Phonemic aspiration is phonetically realized as postaspiration in initial position, as preaspiration in medial and final position: *cop* [k^{h}ohp] 'foam' < > *gob* [kop] 'beak'; *bàta* [ˈpa:hta] 'boat' < > *fàdadh* [ˈfa:tax] 'kindling'.

SG displays considerable dialectal variation, and there is a commensurate degree of variation in the configuration of preaspiration in each dialect, illustrated in (1). Two features are notable: first, in two dialects preaspiration has been lost before certain stops; second, in four dialects, prototypical glottal preaspiration [h] has been supplanted by a velarized variant [x] (Oftedal 1956, Borgstrøm 1974, Ó Baoill 1980, Ó Murchú 1985, Ó Maolalaigh 2007). Upon inspection, asymmetries in these two processes are evident, insofar as they do not apply randomly: each observes a distinct place hierarchy. First, loss of preaspiration ("deaspiration" hereafter) preferentially targets bilabial stops (dialects 2, 3), affecting dental stops only if bilabials are also included: p » t » k. Second, the velar form of preaspiration ("fortition" hereafter) preferentially strikes velar stops, only then extending to dental and perhaps bilabial stops (dialects 3-6): k » t » k.

---

[1] Henceforth, the dental stops will be represented without diacritic.

(1) Preaspiration in six SG dialects



There is no clear reason for this curious state of affairs to obtain in SG. Are there certain features of the articulation of preaspiration that might act as phonetic precursors for each asymmetry: channel bias? Or is there an analytic bias, perhaps originating with a P-map-like phonological module, such that perceptual scales favor certain rankings of faith constraints while discouraging others? Each of these possibilities is assessed in the balance of the paper.

3. SG preaspiration in OT: an overgeneration problem

There are both phonetic and typological reasons to conclude that preaspirated stops are highly marked. Numerous authors have argued that preaspiration is a phonetically problematic feature (Silverman 1997, Kingston 1990, Bladon 1986), especially compared to postaspirated stops. A stop burst, it is argued, is well suited to convey contrastive information, making a postaspiration cue quite robust. Preaspiration, on the other hand, typically follows a sonorant and crucially precedes the stop closure, where airstream pressure has achieved a near-minimal state.

Preaspirated stops are also marked in the typological sense. They are undoubtedly rare: the first UPSID database (Maddieson 1984) identifies 91 languages with voiceless postaspirated stops, but only 2 with preaspirated stops (Goajiro and Ojibwe), from a total sample size of 317 languages. Moreover, there is an implicational asymmetry such that the presence of preaspiration in a language implies that of postaspiration; the reverse is not true (Silverman 2003). Typically, the two segment types are in complementary distribution: postaspirated stops in initial position, preaspirated in medial and final position.[2]

3.1 Analyzing SG preaspiration in standard OT

These facts imply the existence of a set of constraints militating against preaspiration: *[hp], *[ht], *[hk], etc. These constraints must be freely rankable: dialect 2 (p ht hk) implies a high-ranked *[hp], while dialect 4 (hp ht xk) implies a high-ranked *[hk]. However, if anti-preaspiration constraints are freely rankable, a problem arises: a factorial typology predicts more grammars than are attested. But placing the constraints in a fixed ranking leads to the opposite problem, predicting too few grammars.

---

[2] With one possible exception: Mazatec allows initial hC clusters, in which the C may be an obstruent (including oral stops), nasal, or glide (Pike and Pike 1947).

In the following tableaux, both attested and unattested grammars are generated through interaction of anti-preaspiration constraints (collectively labeled *[hT] where appropriate) with MAX (militating against deletion of the preaspiration cue) and IDENT[place] (prohibiting fortition of glottal preaspiration [h] to velarized [x]). Violations of *[hT] are assessed as in (2):

(2) *[hT]: Assign one violation for each sequence of voiceless glottal fricative + voiceless oral stop in the output.

The tableau in (3a) shows that if anti-preaspiration constraints are ranked en bloc below MAX and IDENT[place], glottal preaspiration prevails in all three stops, as in dialect 1 [hp ht hk]; in (3b), ranking *[hT] above IDENT[place] but below MAX permits across the board fortition, but no deaspiration, as in dialect 6 [xp xt xk].

(3) a. dialect 1 [hp ht hk]

/hT/	MAX	ID[place]	*[hT]
☞ hT			*
xT		*!	
T	*!		

b. dialect 6 [xp xt xk]

/hT/	MAX	*[hT]	ID[place]
hT		*!	
☞ xT			*
T	*!		

The remaining configurations of SG preaspirated stops require that place-specific versions of *[hT] be ranked individually. For instance, dialect 4 [hp ht xk] entails that *[hk] only be ranked above IDENT[place], while *[ht] and *[hp] remain low-ranked; MAX remains high-ranked to prevent deaspiration. This is demonstrated in (4a). But if the anti-preaspiration constraints are freely rankable, then *[hp] could just as easily be individually ranked above ID[place] (4b), yielding unattested [xp ht hk] and violating the fortition hierarchy k » t » p.

(4) a. dialect 4 [hp ht xk]

/hk/	MAX	*hk	ID[pl]	*hp	*ht
hk		*!			
☞ xk			*		
k	*!				
/hp ht/					
p t	*!				
xp xt			*!		
☞ hp ht				*	*

b. unattested *[xp ht hk]

/hp/	MAX	*hp	ID[pl]	*ht	*hk
hp		*!			
👎 xp			*		
p	*!				
/ht hk/					
t k	*!				
xt xk			*!		
👎 ht hk				*	*

A similar situation obtains with deaspiration: without fixed rankings, there is nothing to prevent individual anti-preaspiration constraints from being ranked above both MAX and IDENT[place], permitting both [p ht hk] and [hp ht k]—the latter violating the deaspiration hierarchy p » t » k. Thus we have considerable overgeneration without having yet considered alternative repairs such as homorganic frication (/fp st xk/) or substitution of postaspiration for preaspiration, which would also satisfy *[hT].

3.2 The P-map yields fixed rankings of faith constraints

An alternative analysis entails instead that place-specific versions of MAX and IDENT are interacting with a unitary *[hT]. Since preaspiration of velar stops is most resistant to deletion, and that of bilabials least, this would imply the hierarchy in (5a). Meanwhile, IDENT[place] constraints would be arranged in an opposing hierarchy, since preaspiration of velar stops is most vulnerable to fortition, that of bilabial stops least, as in (5b).

(5) a. MAX[h]/_k » MAX [h]/_t » MAX[h]/_p
b. ID[h]/_p » ID[h]/_t » ID[h]/_k

Such rankings could produce both the fortition and deaspiration asymmetries: fortition could never affect bilabials unless dentals and velars were also affected (as attested), and deaspiration could never affect dentals and velars unless bilabials were also affected (again, as attested). The tableau in (6) demonstrates how the fixed ranking in (5a) could generate the grammar of dialect 4 [hp ht xk]: as individual ID constraints are demoted below *[hT], fortition makes its way up the scale, but only in the proper order, i.e. k » t » p.

(6)

/hk/	ID[h] /_p	ID[h] /_t	MAX[h] /_k	MAX[h] /_t	MAX[h] /_p	*hT	ID[h] /_k
k			*!				
☞ xk							*
hk						*!	
/ht/							
t				*!			
xt		*!					
☞ ht						*	
/hp/							
p					*!		
xp	*!						
☞ hp						*	

The question of course is how to motivate such rankings. A ready answer is that they could be motivated by perception: perhaps [hp] sounds most like [p], [hk] least, while [hk] sounds most like [xk], and [hp] least. The P-map provides an excellent means for the formalization of such gradient perceptual effects. According to Steriade (2001b), the P-map is a component of the phonological grammar which incorporates speakers' knowledge of the “relative perceptibility of different contrasts, across the different contexts where they might occur” (p. 1). The P-map thus represents a kind of analytic bias, but one which is fundamentally grounded in phonetics. The problem at this stage, however, is that there is no experimental confirmation of such perceptual scales. Until such confirmation can be obtained (say, through a perception experiment), a P-map analysis of SG preaspiration must remain interesting but provisional.

4. Production experiment: phonetic precursors present in SG

According to the channel bias hypothesis, phonological typology derives from the presence or absence of phonetic precursors: subtle variations in phonetic output which result in the misperception of underlying phonological structure. Such misperceptions may themselves be phonologized. If a preponderance of such errors favors structure X at the expense of Y, and no other factor intervenes, then instances of X will come to outnumber instances of Y, and a typological asymmetry will arise. In other words, “[c]ommon sound patterns typically result from common phonetically motivated sound change” (Blevins 2004, p. 23). Or, more emphatically: “[u]niversal, physical phonetic factors lead to a speech signal which obscures the speaker’s intended pronunciation; listeners may misinterpret ambiguous phonetic elements in the signal and arrive at a pronunciation norm that differs from the speaker’s. This is how sound change works” (Ohala 2005, p. 15).

If the Channel Bias hypothesis is correct, then it should be possible to link the clear typological tendencies in SG preaspiration to phonetic precursors. If they are universal, they should still be present in the language, and amenable to experimental analysis. The balance of this section describes an production experiment conducted to search for such precursors.

4.1 Hypotheses

It is reasonable to surmise that the duration of the preaspiration cue is dependent on the stop’s place of articulation, much like the VOT of normally aspirated stops (Fischer-Jørgensen 1954, Peterson & Lehiste, 1960, Cho & Ladefoged 1999). If the cue in [hp] is shorter than in [hk], the former will be less prominent, hence potentially easier for listeners to miss. This leads to my first hypothesis:

(7) *Duration*: the preaspiration cue is longest in velar stops, shortest in bilabial stops.

It is also possible that speakers sporadically omit the preaspiration cue altogether. Ó Maolalaigh (2007) finds indications of such omission in the data gathered by the Scottish Gaelic Dialect Survey (Ó Dochartaigh 1994-97); moreover, according to the survey results, such omission occurs more commonly before [p] than before [k]. It is thus conceivable that unreliable realization of the preaspiration cue is conducive to a failure of learners to acquire the feature. This is my second hypothesis:

(8) *Frequency*: Phonemically preaspirated stops will occasionally be realized without PA; such omission will occur most frequently before [p], least before [k].

4.2 Participants

Eight native speakers of SG were recruited. Four participants represented dialects 1 [hp ht hk] (the Isle of Lewis), and the remaining four represented dialect 4 [hp ht xk] (the Outer Hebrides other than Lewis, and Skye). The three men and five women ranged from their mid-twenties to early 60's. All participants were literate in the language, and spoke it regularly.

The choice of these two dialects reflected both experimental and pragmatic necessity. First, dialects 1 and 4 are the most conservative, if we assume that the configuration [hp ht hk] is prototypical. Second, these are the only remaining dialects with significant numbers of speakers: the mainland dialects and those of the southern Hebrides are either extinct in the 21st century or have very few remaining speakers, none of whom I was able to locate for the purposes of this study.

4.3 Methods

Thirty-six words were selected in order to exemplify the SG aspirated stops /p^h t^h k^h/ (18) and unaspirated stops /p t k/ (18) in initial position (postaspirated) and in medial and final position (preaspirated). Target segments were also evenly distributed according the phonemic length of the adjacent stressed vowel (±long). A range of vowel qualities was included, though avoiding /i/ because it palatalizes adjacent dental stops in SG. These 36 words were randomized and printed in groups of six, then re-randomized and printed again in groups of six, such that forms appearing list-finally in the first set of 36 were not list-final in the second set of 36. Thus, each word appeared twice, for a total of 72 tokens.

Recordings were made using a laptop computer, the Praat software (Boersma and Weenink 2006), and a desktop USB microphone (frequency response 100 – 16k Hz). Speakers were told that the researcher was interested in a "natural, conversational pronunciation," rather than a "proper" one. Speakers were asked to produce each stimulus within the frame sentence "thubhairt mi __" [hur̥t mi] ("I said __"), yielding a pronunciation approximating a citation form. The duration of each token of preaspiration was measured; omissions by speakers of the preaspiration cue from phonemically aspirated segments were also noted. Praat was set to provide a broadband spectrograph (260 Hz, window length 5 ms), a view range of 6000 Hz, and a dynamic range of 55 dB, ± 5 dB (depending on the quality of the recording).

4.4 Results

Measurements were tested via a mixed linear-regression model to account for multiple observations within subjects. Place of articulation was found to significantly affect the duration of the preaspiration cue, confirming the *Duration* hypothesis:

- preaspiration in labial consonants (avg. 89ms) was shorter than dentals (110ms), *t*(189) = 3.6, *p* = .0004.
- that in dentals (110ms) was shorter than that in velars (138ms), *t*(189) = 3.78, *p* = .0002.

There was also a significant effect for vowel length: as a whole, preaspiration following phonemically long vowels (85ms) was significantly shorter than that following phonemically short vowels (136ms), *t*(189) = -7.38, *p* < .0001. Finally, medial position (91ms) was less favorable to preaspiration than final position (130ms), *t*(189) = 6.62, *p* < .0001. Durational results are summarized in (9a).

The *Frequency* hypothesis was also confirmed. Most speakers sporadically produced unaspirated stops where preaspirated stops were expected, except for one (the older male Lewis speaker), who reliably produced preaspiration in all expected locations. Conditions governing the omission of preaspiration were identical with those affecting duration: omission was most frequent among bilabial stops, after long vowels, and in medial position (9b); when all three conditions were combined (i.e. before bilabial stops, in medial position, and after a long vowel), omission occurred over 70% of the time. (Tokens with omitted preaspiration were not included in the durational averages.)

(9) a. Duration of PA cue, by context b. Omission of phonemic PA (%)

Avg (ms)	Labial	Dental	Velar
	89	110	138

Avg (ms)	VC	V:C	VCV	V:CV
	160	100	112	70

	Labial	Dental	Velar
V:CV	72.2	33.3	6.7
VCV	6.3	21.4	6.3
V:C	20.0	0.0	0.0
VC	8.8	0.0	3.6

5. Discussion

The experiment has revealed two potential precursors for the deaspiration and fortition asymmetries in the typology of SG preaspiration, and thus offers support for the Channel Bias hypothesis. The first potential precursor is that the duration of the preaspiration cue tends to increase as one moves from the bilabial to the velar place of articulation. The second is that phonemically preaspirated stops are frequently realized without preaspiration; again, this happens most frequently in bilabial stops, least frequently in velar stops. Here I discuss how these two precursors may have become phonologized.

There is a reasonable basis for concluding that both the deaspiration and fortition asymmetries have arisen from the place-connected differences in length of the preaspiration cue. In both cases, the asymmetries have likely resulted from the effects these durational differences have on the cue's relative perceptibility in each place of articulation. It is possible that once the duration of preaspiration falls below a certain critical threshold, its value as a cue to the aspiration contrast is obviated. Since the typical duration of the preaspiration cue tends to fall as the PoA of the stop moves forward from velar to dental to bilabial, the reliability with which it meets that threshold may correspondingly fall. As a corollary, speakers may place progressively less value on articulating the cue, even to the point of omitting preaspiration altogether. If this omission happens with sufficient frequency (as in bilabial stops), speakers may assume that the underlying representation contains a plain stop instead of a preaspirated one. The durational differences would ensure that this misperception affected bilabial stops most often, velar stops least, resulting in the deaspiration asymmetry.

Fortition, on the other hand, may be partly attributable to coarticulation, but not entirely. Prototypical preaspiration—unvoiced glottal frication—consists of a nearly unimpeded airstream. As the articulators are approximated preparatory to the closure of a stop, this airstream will become constricted, producing turbulence at the point of articulation. If this turbulence were prominent and frequent enough, a listener may interpret it as intentional frication, rather than incidental, and so it might become phonologized. This explanation is perfectly reasonable in the case of /hk/ > /xk/, where coarticulation effects on the preaspiration cue may have rendered it difficult to distinguish from the previously existing, non-preaspiration related /xk/ cluster. It would also neatly explain fortition to homorganic fricative-stop sequences, i.e. /fp st xk/, as in Fox (Silverman 2003). But coarticulation cannot explain SG /hp xt xk/ (dialect 5), and especially not /xp xt xk/ (dialect 6), where prototypical glottal preaspiration has given way to the velar fricative form exclusively.

Misperception may provide an explanation. A key factor in distinguishing place of articulation in fricatives is the location of their spectral peaks: "backer fricatives have greater noise at lower frequencies in keeping with the longer anterior cavity associated with relatively posterior [place of articulation]" (Gordon, Barthmaier, & Sands 2002, p. 167); labial and interdental fricatives, on the other hand, are distinguished by their flat spectra with no notable peaks. Substituting [x] for [h] would therefore entail a relatively minimal perceptual adjustment, compared to other oral fricatives. Further, the overall amplitude of [x] is substantially greater than that of [h], enhancing its perceptual value. Thus, if motivated to repair violations to *[hT], speakers would find [xp xt xk] to be more suitable perceptually than [fp st xk].

It is also of interest why place of articulation should affect the duration of the preaspiration cue in the first place. Ladefoged, Ladefoged, Turk, Hind, & Skilton (1998) offer two explanations. First, anatomy may play a role: since in velar stops, the contact between articulators during the closure extends over a greater space than that in dental or bilabial stops, the release of this closure takes a concomitantly greater period of time. Second, since the body of air in front a velar closure is greater than that before a dental or bilabial closure, the period of time required for it to begin vibrating is longer. Furthermore, the pressure behind a velar stop may be higher (due to the smaller cavity there), and again, it may require more time for the pressure differential across the glottis to drop sufficiently for phonation to commence. Of these two explanations, the first seems most plausible: the articulators involved are the same for both postaspiration and preaspiration. However, though a larger cavity takes more time than a smaller one to commence vibrating *after* a closure, it does not necessarily need more time to cease vibrating *before* a closure (as in preaspiration).

A final question follows from the hypothesis that a physiological predisposition is at work. Such a predisposition should apply equally well in any language with preaspirated stops. So far as I am aware, however, no deaspiration asymmetry, or anything like it, has been reported in any other preaspirating language. A desideratum, then, is an exploration of PoA-related durational effects in other languages, to learn whether similar tendencies are to be found outside of SG, even at the subphonemic level.

6. Conclusions

First, this paper has illustrated two typological asymmetries in SG preaspirated voiceless stops. The first asymmetry involves *deaspiration*, or the loss of preaspiration; deaspiration preferentially targets bilabial stops, but leaves velar stops untouched. The second asymmetry involves *fortition*, in which preaspiration is realized as the voiceless velar fricative [x] instead of the glottal fricative [h]; fortition overwhelmingly targets velar stops, while affecting dental and bilabial preaspirated stops to a lesser extent. Both deaspiration and fortition were identified as repairs to the posited constraint *[hT], which militates against preaspiration, a cross-linguistically highly marked phonological feature.

This paper has shown that a standard Optimality-Theoretic account of SG preaspiration results in substantial overgeneration. This overgeneration can be constrained using an analysis based on the P-map hypothesis (Steriade 2001a). However, the P-map based analysis may be criticized as ad hoc, since it depends crucially on the existence of as-yet independently confirmed perceptual scales. Thus, analytic bias remains unsupported as an explanation for typological asymmetries in SG preaspiration.

By contrast, this paper provides strong evidence for channel bias. A production experiment identified robust phonetic precursors to both asymmetries. These precursors consist of sharp variation in the duration of preaspiration and optional omission of the preaspiration cue. Both the duration and optional omission of preaspiration correlate with place of articulation, such that the duration of the preaspiration cue is shortest, and optional deaspiration most common, in bilabial stops; conversely, the duration of preaspiration is longest, and optional deaspiration least frequent, in velar stops.

The paper illustrates the need for further research on two points. First, a perception study is needed to test for perceptual scales like those entailed by the provisional P-map analysis presented here. Without empirical confirmation of such scales, the fixed constraint rankings on which the analysis depends are fatally ad hoc. Confirmation of such scales would be indicate a case of analytic bias mimicking channel bias; cf. Wilson (2006), which finds that velar palatalization has both analytic and channel bias correlates. Second, if durational differences connected with place of articulation are physical in nature, they ought to be universal; further research should be directed toward establishing whether similar asymmetries attributable to these factors exist at the phonological or subphonemic level in other languages, particularly those that exhibit preaspiration.

References

Bladon, A. 1986. Phonetics for hearers. In G. MacGregor, ed. *Language for hearers.* Oxford: Pergamon. p. 1-24.

Blevins, Juliette. 2004. *Evolutionary Phonology*. Cambridge: Cambridge University Press.

Boersma, Paul & David Weenink. 2006. *Praat: doing phonetics by computer* (Version 4.5.01) [Computer program]. Retrieved December 5, 2006, from http://www.praat.org/.

Borgstrøm, Carl HJ. (1974). On the influence of Norse on Scottish Gaelic. *Norsk Tidsskrift for Sprogvidenskap* suppl. vol. XI. Oslo: H. Aschehoug & Co. p. 91-103.

Cho, Taehong and Peter Ladefoged. 1999. Variation and universals in VOT: evidence from 18 languages. *Journal of Phonetics*, 27:207-229

Fischer-Jørgensen, Eli. (1954). Acoustic analysis of stop consonants. *Miscellanea Phonetica*, 2:42-59.

Gordon, Matthew, Paul Barthmaier, and Kathy Sands. 2002. A cross-linguistic study of voiceless fricatives. *Journal of the International Phonetic Association*, 32:141-174.

Johnson, Keith. 2003. *Acoustic and Auditory Phonetics.* Oxford: Blackwell.

Kingston, John. 1990. Articulatory binding. In John Kingston and Mary E. Beckman, eds. *Papers in Laboratory Phonology 1: between the grammar and physics of speech.* Cambridge: CUP. p. 406-434.

Kiparsky, Paul. 2006. The amphichronic program vs. Evolutionary Phonology. *Theoretical Linguistics*, 32:217–236.

Ladefoged, Peter, Jenny Ladefoged, Alice Turk, Kevin Hind, & St. John Skilton. 1998. Phonetic structures of Scottish Gaelic. *Journal of the International Phonetic Association*, 28:1-41.

Ladefoged, Peter. and Ian Maddieson. 1996. *Sounds of the world's languages.* Oxford: Blackwell.

Lamb, William. 2001. *Scottish Gaelic.* Munich: LINCOM Europa.

Maddieson, Ian. 1984. *Patterns of sounds.* Cambridge: CUP.

Moreton, Elliott. 2008a. Analytic bias and phonological typology. *Phonology*, 25:83-127.

Moreton, Elliott. 2008b. Learning bias as a factor in phonological typology. In Charles Chang and Anna Haynie, eds. *Proceedings of the 26th Meeting of the West Coast Conference on Formal Linguistics* (WCCFL). p. 393--401.

Myers, Scott. 2002. Gaps in factorial typology: The case of voicing in consonant clusters. Ms., University of Texas at Austin.

Ó Baoill, Dónall. 1980. Preaspiration, epenthesis, and vowel lengthening—interrelated and of similar origin? *Celtica*, 13:79-108.

Ó Dochartaigh, Cathair. 1994-1997. *Survey of the Gaelic dialects of Scotland: questionnaire materials collected for the Linguistic Survey of Scotland.* Vols. 1-5. Dublin: Dublin Institute for Advanced Studies.

Ó Maolalaigh, Roibeard. 2007. Preaspiration in Scottish Gaelic Dialects. Ms., University of Glasgow.

Ó Murchú, Máirtín. 1985. Varia VIII: Devoicing and pre-aspiration in varieties of Scots Gaelic. *Ériu*, 36:195-198.

Oftedal, Magne. 1956. *The Gaelic of Leurbost Isle of Lewis: A Linguistic Survey of the Gaelic Dialects of Scotland* vol III. *Norsk Tidsskrift for Sprogvidenskap* suppl. bind IV. Oslo: H. Aschehoug & Co.

Ohala, John. J. 2005. Phonetic explanations for sound patterns: implications for grammars of competence. In William J. Hardcastle & Janet M. Beck, eds. *A figure of speech: a festschrift for John Laver*. London: Erlbaum. p. 23-38.

Pater, Joseph. 1996. Austronesian Nasal Substitution and other NC effects. In René Kager, Harry van der Hulst, and Wim Zonneveld, eds. *The prosody morphology interface*. Cambridge: Cambridge University Press. p. 310-343.

Peterson, Gordon E. & Ilse Lehiste. 1960. Duration of syllable nuclei in English. *Journal of the Acoustical Society of America*, 32:69-703.

Pike, Kenneth L., and Eunice V. Pike. 1947. Immediate constituents of Mazateco syllables. *International Journal of American Linguistics*, 13:78-91.

Silverman, Daniel. 2003. On the rarity of pre-aspirated stops. *Journal of Linguistics*, 39:575-598.

Silverman, Daniel. 1997. *Phasing and recoverability.* PhD dissertation. New York: Garland.

Steriade, Donca. 2001a. Directional asymmetries in place assimilation. In Elizabeth Hume and Keith Johnson, eds. *The role of speech perception in phonology.* San Diego: Academic Press. p. 219-250.

Steriade, Donca. 2001b. The phonology of perceptibility effects: the P-map and its consequences for constraint organization. Ms., University of California, Los Angeles.

Wilson, Colin. 2006. Learning phonology with substantive bias: an experimental and computational study of velar palatalization. *Cognitive Science*, 30:945–982.

Wilson, Colin. 2003. Analytic bias in artificial phonology learning: consonant harmony vs. random alternation. Handout from presentation at the Workshop on Markedness and the Lexicon, Massachusetts Institute of Technology, January 25, 2003.

Department of Linguistics
University of North Carolina
104A Smith Building, CB #3155
Chapel Hill, NC 27599

iclayton@email.unc.edu