

Analytic Bias as a Factor in Phonological Typology

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1. Introduction¹

Why are some phonological patterns common across unrelated languages, while others are rare or nonexistent? The common patterns must be either innovated more often, or lost less often. The focus of this study is on two major proposals as to the factors determining the innovation and retention rates. One is *analytic bias*, cognitive biases, such as Universal Grammar, which facilitate the learning of some patterns and inhibit that of others (e.g., Chomsky & Halle 1968:4, 251, 296–297; Prince & Smolensky 1993:3, 201–202; Steriade 2001:235–237).

The other is *channel bias*, systematic phonetic errors in the transmission of individual utterances which, by corrupting the learner's received corpus, favor innovation of some patterns and extinction of others. Channel-bias theories of typology assign a major role to *phonetic precursors*—subtle phonetic interactions which give rise to phonological patterns when their effects are interpreted as phonological (Hyman 1976), with more robust precursors leading to more frequent phonologization (Ohala 1994a; Hale & Reiss 2000; Barnes 2002:151–159; Kavitskaya 2002:123–133; Blevins 2004:108–109). In such theories, UG may supply representational units, or regularize variability, but it does not otherwise favor one phonological pattern over another (Ohala 1990, 2005; Hale & Reiss 2000; Hume & Johnson 2001; Kochetov 2002:186, 216, 226; Blevins 2004:19–21, 41, 281–285).

Analytic and channel bias effects can be hard to distinguish on the basis of typological data alone. For example, vowel height harmony is common, while consonant continuancy harmony is unknown (Rose & Walker 2004). This asymmetry can be accounted for in terms of analytic bias if we posit that UG includes a constraint AGREE-[HIGH] which can drive height harmony (Bakovic 2000), but no AGREE-[CONT]. However, a channel-bias explanation is possible too (after Ohala 1994b; Beddor et al. 2001; Blevins 2004:142–144; Przewdzicki 2005): vowel height coarticulation can serve as a phonetic precursor for height harmony, but there is no precursor for continuancy harmony. Both explanations are possible; the solution is underdetermined by the typological data.

This study asks whether analytic bias can cause a typological asymmetry when channel bias is controlled. Evidence is presented that (1) phonological height-height dependencies, such as vowel-height harmony, outnumber height-voice dependencies; (2) their phonetic precursors do not differ in magnitude; and (3) a height-height pattern is learned more easily in the lab than a height-voice pattern.

The novelty of these results is that they pin a typological fact squarely on analytic bias by controlling for channel bias. Previous lab work on analytic bias focused on "phonetically natural" analytic biases, which are by definition confounded with channel biases (e.g., Schane et al. 1974; Pycha, Nowak, Shin, & Shosted 2003; Wilson 2006). Previous studies which eliminated channel bias inferred an analytic bias, but did not demonstrate it directly in the lab (Kiparsky 1995, 2004, 2006).

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2. Typology: Height-height outnumbers height-voice

The typological asymmetry at issue here is that between phonological "height-height" patterns (dependency between the height of vowels in adjacent syllables, such as height harmony or height disharmony), and phonological "height-voice" patterns (dependency between the height of a vowel and the phonological voicing status of an immediately following obstruent). It was hypothesized, on the basis of informal lore, that the former are typologically more frequent than the latter. The hypothesis was tested by means of a brute-force search through published grammars, subject to the following criteria. First, it was limited to languages in which both patterns had the opportunity to occur, i.e., languages described as having a voicing, aspiration, or fortis/lenis contrast in obstruents. Second, to insure that a pattern was genuinely phonological rather than phonetic, it had to neutralize a contrast found elsewhere in the language. Thus, static phonotactic patterns and morphophonemic alternations qualified, but allophonic alternations did not. Third, alternations limited to individual morphemes did not qualify. Fourth, languages in the survey must have been described from work with living speakers. Fifth, as a guard against double-counting cases of common inheritance, the survey counted language families (defined as top-level Ethnologue categories, Gordon 2005) rather than individual languages.

Height-height patterns were found in 5 families. *Basque*: In many dialects, /a/ raises to /e/ after a syllable containing a high vowel (voicing contrast; Hualde 1991:10, 23–31). *Indo-European*: In Buchan Scots, unstressed suffixal high vowels become non-high after a stressed non-high vowels (voicing contrast; Paster 2004). *Niger-Congo*: In c'Lela, roots do not mix high and non-high vowels; suffixes alternate (voicing contrast; Dettweiler 2000). *Oto-Manguean*: In Maltinaltepec Tlapaneca, /a/ is unrestricted, but vowels of non-final syllables are mid or high depending on whether the final vowel is mid (voicing contrast; Suaréz 1983:7–9, 12–16, 20–22, 48–49). *Sino-Tibetan*: In Lhasa Tibetan, non-high vowels become high in the presence of a high vowel (aspiration contrast in stops; Dawson 1982:3, 11–12, 63–80). If we relax the criteria somewhat, we can add 4 more marginal cases. *Afro-Asiatic*: In Kera, non-high vowels become high in the presence of a high vowel. The "voicing" difference in stops is really aspiration. Research in the 1970s reported that it was contrastive, but more recent and detailed fieldwork did not replicate this finding (Ebert 1976, 1979:14–18, Pearce 2003, 2005, p.c. 2007). *Austronesian*: In Woleaian, /a/, the only low vowel, becomes [e] before a syllable containing [a], and also becomes [e] between two syllables containing high vowels (voicing contrast marginal, only /s/ vs /z/; Sohn 1971, 1975). *Chukotko-Kamchatkan*: In Chukchee, /i u e/ lower to /e o a/ when in the same morphological constituent as /e o/ or some kinds of /ə/ (voicing contrast marginal: /k/ vs. /g/ only; Bogoras 1922 [1969]. Later authors describe the /g/ as /ɣ/, making voicing redundant with continuancy: Kämpfe & Volodin 1995). *Gulf*: In Tunica, mid vowels do not co-occur in underived lexical items. /e o/ lower to /ɛ ɔ/ before /a/ in same morpheme (voicing contrast marginal, mostly in loans; height contrast in mid vowels dubious; Haas 1946, Wiswall 1981:82–125).

Height-voice patterns fitting the criteria were not found in any family. Marginal cases occurred in two families. One was *Sino-Tibetan*. Lungtu Fujien Chinese stops contrast for aspiration in onset. In codas, voiced stops occur after nonlow vowels, voiceless stops after low vowels. The coda voiced/voiceless contrast is redundant with preglottalised/glottalised, and not phonemically contrastive (Egerod 1956:27–51). The other was *Indo-European*, with two possible cases. In Polish, /ɔ/ raises to [o] before underlyingly voiced non-nasal codas in many lexical items. Productivity is doubtful (Sanders 2003). In many dialects of English, [ʌɪ] is found only before voiceless codas and [aɪ] is found only elsewhere. The phonemic contrast between [ʌɪ] and [aɪ] is marginal, being found only before [r] (Chambers 1973).

Thus, height-height patterns outnumber height-voice patterns in the survey by 5 to 0, or 9 to 2 if the marginal cases are admitted. This is surprising when we consider that the height-voice patterns relate phonetically adjacent elements, while the height-height patterns relate phonetically remote ones.

3. Phonetics: Precursors have about the same size

The high typological frequency of vowel harmony has been ascribed to channel bias caused by its phonetic precursor, vowel-to-vowel height coarticulation (Ohala 1994b; Blevins 2004:143;

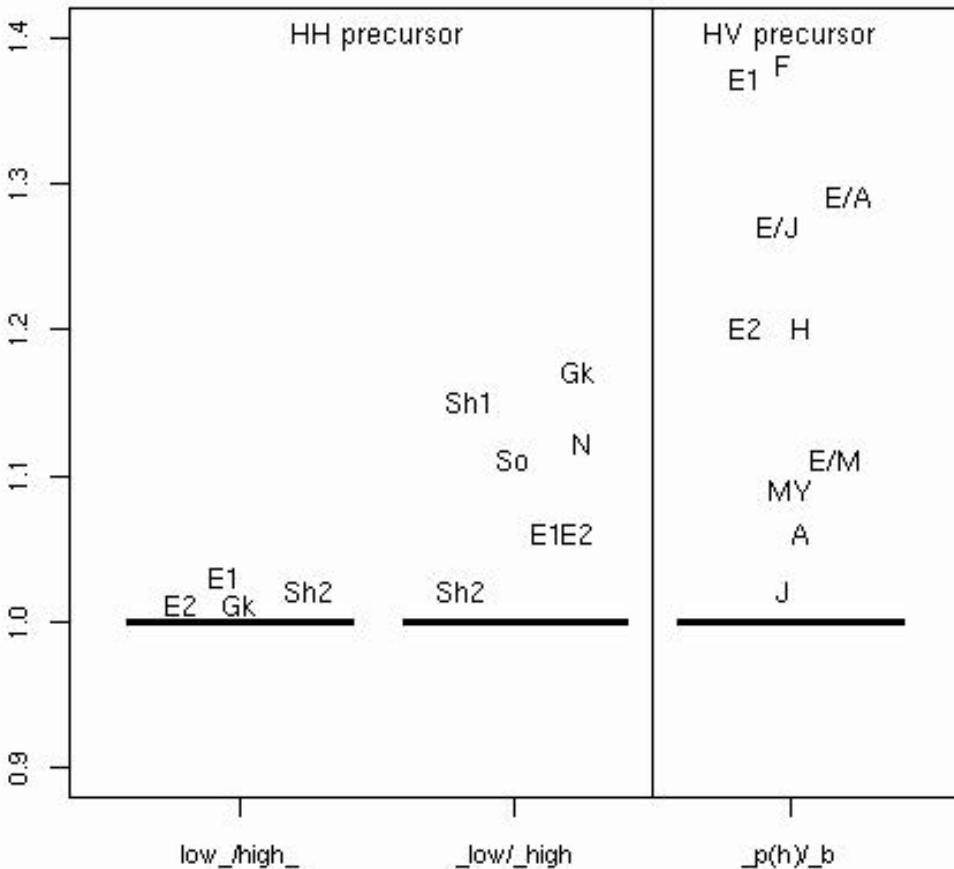
Przedziecki 2005). If that is so, then the phonetic precursor of the height-voice pattern should be smaller than that of the height-height pattern.

The height-height precursor is, uncontroversially, vowel-to-vowel height coarticulation, expressed acoustically as a perturbation in the F1 value of a vowel depending on the height of its neighbor. The height-voice precursor is more obscure. The existence of a correlation between vowel F1 and the voicing, aspiration, or fortis/lenis status of a following consonant is not in dispute, but its origins are still incompletely understood (for discussion, see Kingston & Diehl 1994; Thomas 2000; Moreton 2004). For the purposes of this study, the correlation was accepted as an unanalyzed fact.

A survey was undertaken to compare the effects on vowel F1 of contextual height and voicing, aspiration, or fortis/lenis status. Published studies were located where vowel F1 was measured in the relevant contexts. The contexts likeliest to raise or lower target F1 were identified. For height-height studies, the Raising context was taken to be high vowels and the Lowering context was low vowels. For height-voice studies, the Raising context was voiced/unaspirated/lenis and the Lowering context is voiceless/aspirated/fortis. The effect of context was defined to be target F1 in the Raising context divided by that in the Lowering context. (This automatically normalizes away inter-speaker differences in F1 range.) If the study made measurements at multiple points in the target vowel, the point closest to the context was used.

The results are plotted in (1). The vertical axis shows the effect of context (F1 in the Raising context divided by F1 in the Lowering context). A value of 1 indicates no effect; higher values mean that F1 was higher in the Raising context. Each symbol represents one study of one language. Sources and numerical values are tabulated in (2) and (3).

(1) Height-height and height-voice precursor magnitudes compared. Vertical axis shows ratio between F1 in the Raising context (high vowel, or voiced/unaspirated/lenis obstruent) and F1 in the Lowering context (low vowel, or voiceless/unaspirated/fortis obstruent). See text.



(2) Phonetic effect of context vowel height on target vowel F1.

Code	Study	Ratio
E1	English (Beddor et al. 2002): 5 speakers. Stressed /i e a o u/. Measured at target offset: [_Ca] vs. [_Ci]: Measured at target onset: [aC_] vs. [iC_]:	1.06 1.03
E2	English (Koenig & Okalidou 2003): 3 speakers. Stressed /i e a o u/, at steady state. [_Ca] vs. [_Ci]: [aC_] vs. [iC_]:	1.01 1.02
Gk	Greek (Koenig & Okalidou 2003): 3 speakers. Stressed /i e a o u/, at steady state. [_Ca] vs. [_Ci]: [aC_] vs. [iC_]:	1.17 1.01
N	Ndebele (Manuel 1990): 3 speakers. /e/ and /a/ at target offset. [_Ca] vs. [_Ci]:	1.12
Sh1	Shona (Manuel 1990): 3 speakers. /e/ and /a/ at target offset. [_Ca] vs. [_Ci]:	1.15
Sh2	Shona (Beddor et al. 2002): 7 speakers. Stressed /i e a o u/. Measured at target offset: [_Ca] vs. [_Ci]: Measured at target onset: [aC_] vs. [iC_]:	1.02 1.02
So	Sotho (Manuel 1990): 3 speakers. /e/ and /a/ at target offset. [_Ca] vs. [_Ci]:	1.11

(3) Phonetic effect of context consonant voicing or aspiration on target vowel F1.

Code	Study	Ratio
A	Arabic (De Jong & Zawaydeh 2002: Figure 5): Stressed /a/ at midpoint. [_t] vs. [_d]:	1.05
E1	English (Wolf 1978): 2 speakers, /æ/. Average F1 in last 30 ms. [_p/t/k] vs. [_b/d/g]:	1.37
E2	English (Summers 1987): 3 speakers. /æ a/ at vowel offset: [_p/f] vs. [_b/v]:	1.20
E/A	L2 English (L1 = Arabic) (Crowther & Mann 1992): 10 speakers. /a/ measured at vowel offset, [_t] vs. [_d]:	1.29
E/J	L2 English (L1 = Japanese) (Crowther & Mann 1992): 10 speakers. /a/ measured at vowel offset, [_t] vs. [_d]:	1.27
E/M	L2 English (L1 = Mandarin) (Crowther & Mann 1992): 10 speakers. /a/ measured at vowel offset, [_t] vs. [_d]:	1.11
F	French (Fischer-Jørgensen 1972): 1 speaker. /a/ just before closure. [_p/t/k] vs. [_b/d/g]:	1.38
H	Hindi (Lampp & Reklis 2004): 5 speakers. /ɔ/ just before closure. [_k] vs. [_g]:	1.16
J	Japanese (Kawahara 2005): 3 speakers. /e a o/ just before closure. [_p/t/k] vs. [_b/d/g]:	1.02
MY	Mòbà Yoruba (Przedzdiecki 2005): 1 speaker. /i/ at midpoint. [_t/k] vs. [_d/g]:	1.09

Although the phonological height-height patterns are typologically more frequent than the height-voice patterns, there is no evidence that the height-height precursor is larger than the height-voice one; if anything, the reverse seems to be true. The height-voice precursor is *underphonologized* relative to the height-height precursor. This is not an isolated instance. Vowel intrinsic F0 seems to be underphonologized relative to voice-F0 interaction (Hombert et al. 1979). Tone-tone patterns, too, are more common than voice-tone patterns (20 Ethnologue families vs. 8), but their phonetic

precursors—about which much more phonetic data is available than in the height-height/height-voice case—have similar magnitude (Moreton, to appear). Thus, precursor robustness does not in general predict typological frequency, and does not provide a general explanation for it.

4. Experiment 1: Height-height vs. height-voice

With precursor robustness unable to explain the height-height/height-voice typological asymmetry, it is the turn of analytic bias: are phonological height-height patterns easier to learn than height-voice patterns?

Patterns of segmental occurrence and co-occurrence can be acquired by learners in laboratory experiments. Pattern-conformity effects have been found with adults in a number of task situations (e.g. Schane et al. 1974; Dell et al. 2000; Onishi et al. 2002; Pycha et al. 2003; Wilson 2006) and with infants in preferential listening (Saffran & Thiessen 2003; Chambers et al. 2003).

A pattern-learning experiment was designed to test the hypothesis that height-height patterns would be easier to learn. Each pattern was instantiated using a set of CVCV stimulus "words" with the inventory /t k d g/ and /i u æ ɔ/, spoken by the MBROLA synthesizer (Dutoit et al. 1996) using an American English voice (*us3*). In the "HH Language", vowels agreed in height, instantiating the height-harmony pattern. In the "HV Language", the first vowel was high if and only if the second consonant was voiced. This represents what *would* be phonologization of the HV precursor.

The experiment consisted of a "Study Phase" and a "Test Phase". In the Study Phase, each trial consisted of listening to a randomly chosen word of one Language through headphones, and repeating it into a microphone. Each word recurred 4 times in the Study Phase, for a total of 128 trials. In the Test Phase, each of the 32 trials consisted of listening to a pair of novel words, only one of which conformed to the Language pattern. Participants were asked to "choose the one that you think was in the language you studied". A 3-minute break with instrumental music followed, and then each participant repeated the procedure for the other Language. Each of the two Languages used 32 "words" for the training phase and 64 for the test phase. Each participant got their own randomly-selected HV and HH Languages, which contained no words in common. The design is shown in (4).

(4) Stimulus design for Experiment 1.

(a) Stimuli for HV Language

Stimulus variables			Test Phase	
HV-conforming	HH-conforming	Study Phase	Positive	Negative
+	+	16	16	—
+	—	16	16	—
—	+	—	—	—
—	—	—	—	32

(b) Stimuli for HH Language

Stimulus variables			Test Phase	
HV-conforming	HH-conforming	Study Phase	Positive	Negative
+	+	16	16	—
+	—	—	—	—
—	+	16	16	—
—	—	—	—	32

All Study items matched the pattern of the Language condition, and were 50% likely to match or mismatch the pattern of the other Language condition. The same was true for the positive Test items. The negative Test items had the same properties in both Language conditions. In both Languages, all of the permitted HV and HH sequences occurred with equal frequency. (This design does *not* test generalization to new vowels; i.e., it does not distinguish between learning vowel harmony and learning a list of vowel-vowel patterns.) Participants were 24 native American English speakers, of whom 12 did the HV Language first and 12 did the HH Language first.

The dependent measure was the probability of choosing the correct Test stimulus. The results were analyzed in a mixed-effects logistic regression model with a random intercept for each participant, using the R software (R Development Core Team, 2005). The initial model had fixed-effect terms for Condition (HH or HV Study Language), HH-Nonconformity (whether the correct response was HH-conforming), HV-Nonconformity (ditto), Order (which Language came first), and all possible interactions. The model was reduced by deleting terms until the next model would have differed from the initial model at $p < 0.25$ by analysis of deviance. The final model is shown in (5):

(5) Final (reduced) model for Experiment 1.

Variable	Coefficient	SE	z	$P(> z)$	
HV (intercept)	0.1693	0.0862	1.964	0.0496	*
HH difference from HV	0.5087	0.1307	3.892	<0.00001	***
HV-Nonconformity	-0.2608	0.1508	-1.729	0.0838	

Performance in the HV condition was marginally better than chance, whereas performance in the HH condition was much better than that in the HV condition. These results are in line with the hypothesis that height-height patterns are easier to learn than height-voice patterns. There was no significant effect of HH- or HV-Nonconformity, i.e., participants trained on the HH Language had no preference between HV-conforming and HV-nonconforming Test items, and vice versa. This indicates that the participants did not come into the experiment with any pre-existing preference for HH- or HV-conforming items, and hence that the difference in performance between the HH and HV conditions was due to learning in the Study Phase.

Thus, we have seen that there is a typological asymmetry favoring height-height over height-voice patterns in phonology, that the asymmetry does not reflect a difference in the robustness of the two phonetic precursors, and that the height-height pattern is learned more readily in the lab. These results favor analytic bias over precursor robustness as an explanation for the typological asymmetry.

5. Experiment 2: Height-voice vs. voice-voice

What difference between the HH and HV conditions led to the difference in learning? Experiment 1 left several possibilities open. One, uninteresting but dangerous, is that participants couldn't hear the voicing on the medial stops well enough to detect the pattern. This possibility was tested using a blind-coded random sample of 500 voice responses from the Study Phase of Experiment 1. The medial stop was successfully recorded in 364 of them (in the others, the participant clicked "Next" before finishing the utterance, or the microphone recorded an insufficient signal). The transcribed response differed from the stimulus in voicing in only 4 cases, or 1.1%.

A second possibility is that the patterns favored by analytic bias are precisely the ones which are typologically common, as would be expected if analytic bias is the *only* determiner of typological frequency. If that is correct, then a voice-voice pattern should have no advantage over a height-voice pattern, since both are typologically rare (Hansson 2004; Rose & Walker 2004).

Finally, analytic bias may favor height-height over height-voice in some more general way: as a single-feature dependency (Chomsky & Halle 1968:334–335), a within-tier dependency (Newport & Aslin 2004), or a dependency between phonologically similar segments (Frisch et al. 2004; Rose & Walker 2004). If so, a voice-voice pattern should be learned more easily than a height-voice pattern.

In Experiment 2, the HH Language of Experiment 1 was replaced by a "VV Language", in which the two stop consonants agreed in voicing. The results are shown in (6):

(6) Final (reduced) model for Experiment 2.

Variable	Coefficient	SE	z	$P(> z)$	
HV (Intercept)	0.1986	0.1032	1.9250	0.0542	
VV difference from HV	0.3013	0.1478	2.0378	0.0416	*
Order=2nd	-0.1116	0.1529	-0.7298	0.4650	
Order=2nd \times Condition=VV	-0.4565	0.2158	-2.1153	0.0344	*

Performance in the HV condition just missed significance at the conventional 5% level. Performance in the VV condition was significantly better, though not by as much as the HH condition in Experiment 1. The only other significant term in the final model was an interaction between Order and Condition, showing that the difference between the HV and VV conditions disappeared in the second half of the experiment.

Although these results are not as clear-cut as those of Experiment 1, they do suggest that there is a difference in analytic bias between the VV and HV experimental patterns. It follows that a difference in analytic bias need not entail a corresponding difference in typological frequency; or, put a different way, that analytic bias is not the only important factor determining typological frequency.

6. Discussion

Differences in precursor robustness do not translate directly into differences in typological frequency: height-height patterns are more frequent than height-voice patterns, despite their similar-sized precursors. Similar findings have been reported for voice-tone vs. height-tone (Hombert et al. 1979) and tone-tone vs. voice-tone (Moreton, to appear). Hence, typology does not just emerge from indiscriminate phonologization by an indifferent learner (contra Ohala 1990, 1993, 2005; Hale & Reiss 2000; Hume & Johnson 2001; Blevins 2004:19–21, 41, 281–285). Some other factor intervenes, biasing either the rates at which precursors become phonologized, or the rates at which established phonological patterns survive from generation to generation.

Experiment 1 demonstrated a learning bias which, if it operates in nature the same way it does in the lab, could lead to the observed typological skew. This indicates that typology can be shaped by analytic bias in ways that cannot be explained by precursor robustness. And if analytic bias can affect typology when precursor robustness is equal, it may also affect typology when precursor robustness is *unequal*, e.g., by enhancing the phonologization of a precursor.

Experiment 2 found evidence of a learning bias which never has a chance to apply in nature: a voice-voice pattern is easy to learn compared to a height-voice pattern, but the lack of phonetic precursors obscures the typological effect. Thus, typology can be shaped by precursor robustness in ways that cannot be explained by analytic bias (Myers 2002).

Any adequate theory of typology, therefore, will have to incorporate both factors (Kiparsky 2005, 2006; see also Blevins 2006b:246). Some typology may result from channel bias, some from analytic bias, and some from their interaction. In pursuit of a general theory of precisely what the biases are and how they shape typology, it will be easiest to start with cases where the two do *not* interact, and study each one in isolation. An efficient strategy for finding such cases is to look for mismatches between phonetic and phonological typology—both underphonologization, in which a robust precursor persistently fails to be phonologized, and overphonologization, in which a phonological pattern is innovated in the absence of a precursor. The analytic biases underlying these cases can then (we hope) be mapped in the lab and modeled in the abstract (e.g., how does UG, or the learning algorithm, *make* some patterns easier to learn?—Wilson 2006; Moreton, to appear). More precise knowledge of what the analytic biases are will in turn highlight mismatches between them and typology, as in the present Experiment 2, pointing to cases where channel bias may be the main factor.

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