Inductive Bias against Stem Changes as Perseveration: Experimental Evidence for an Articulatory Approach to Output-Output Faithfulness

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Abstract

Speakers of morphologically-rich languages commonly face what has been called the Paradigm Cell Filling Problem: they know some form of a word but it is inappropriate to the current context, leading them to derive a form of that word they have never encountered (e.g., they know the singular form of a noun, and now need to produce the plural). We suggest that in performing this task speakers perseverate on articulatory gestures comprising the form they know, and that gestures vary in the extent to which speakers perseverate on them. This proposal explains the parallels between findings in loanword adaptation, speech errors, and acquisition of phonology. New experimental data from a miniature artificial language are presented in support of the theory.

Keywords: Phonology; morphology; speech production; inductive bias; faithfulness; Harmonic Grammar.

Theory

In a seminal paper arguing for substantive bias in the acquisition of phonology, Wilson (2006) defines "substance" as "any aspect of grammar that has its basis in the physical properties of speech. These properties include articulatory inertias, aerodynamic pressures, and degrees of auditory salience and distinctiveness" (p. 946). In other words, substance in phonology is phonetics. The Substantive Bias Hypothesis suggests that the learner of phonology is predisposed towards acquiring patterns that are phonetically natural. Phonetically unnatural patterns *are* learnable and can therefore be productive in natural languages (Mielke, 2008; Ohala, 1978) but the learner needs more evidence to be convinced of their reality (Wilson, 2006).

A *natural phonological alternation* can be defined as an articulatorily and/or perceptually minimal change in a context where it can result from coarticulation, articulatory undershoot, and/or misperception. For instance, the velar stop [k] might become [tʃ] before [i] because the coarticulation between [k] and [i] causes [k] to front (becoming [k^{j}]), resulting in [k^{j}i], which is easy to misperceive as [tʃi] in noise (Guion, 1998). There are therefore multiple ways in which a phonological alternation can be phonetically unnatural.

First, it might happen in the "wrong" context. If it happens in the wrong context, it also might not happen in the "right" context, making it even more unnatural. For instance, palatalization might happen before [o] without happening before [i] (Kapatsinski, 2010) despite [ko] and [tʃo] being acoustically and articulatorily quite distinct whereas [k^{j}i] and [tʃi] are very similar. Context naturalness has been investigated experimentally by Mitrovic (2012), Schane et al. (1975), and Wilson (2006), among others.

Second, the change itself might be unnatural. For instance, Ohala (1978) shows that Southern Bantu changes [p] into [tʃ] without changing [k] into [tʃ].[1] The articulatory difference between [p] and [tʃ] is articulatorily greater than the one between [k] and [tʃ]. Nonetheless, [p] changes into [tʃ] in Southern Bantu whereas [k] does not. The influence of *change naturalness* on learnability has only now begun to receive attention (Kapatsinski 2012b, White 2012). In demonstrating an effect of change naturalness, we provide additional evidence for the existence of substantive bias (contra Blevins, 2004; Hale & Reiss, 2000; and Ohala, 1990 among others).

How can change naturalness influence learnability? We propose that it is through *perseveration* in speech production. Consider a speaker who knows one form of a word (say, a singular) and wants to come up with another form of the same word (say, a plural). We propose that in producing the unknown wordform the speaker is likely to perseverate on the articulatory units of the known wordform (Kapatsinski, 2013). This perseveration is usually functional, in that most, if not all, of the known form *should be* in the to-be-produced unknown form. This type of perseveration may help humans avoid bizarrely unfaithful

[1] The Southern Bantu alternation context is also unnatural: palatalization happens before [w] rather than a front vowel (Ohala, 1978).

mappings like *mail-membled*, demonstrated by Rumelhart & McClelland's (1986) model of English past tense formation, which lacks perseveration and is fully empowered to learn arbitrary present-past pairings. However, when the mapping between the known form and the to-be-produced form involves a stem change, perseveration on the to-be-produced form can result in error, where the stem change is leveled (or at least partially leveled). For instance, Kapatsinski (2009) showed that subjects who are exposed to a miniature artificial language with velar palatalization (k→tʃ before the plural suffix -i) often make errors in which [k] becomes [ktʃ] rather than [tʃ] before -i (e.g., flʊʊk→flʊʊktʃi rather than flʊʊk→flʊʊtʃi), erroneously retaining the final consonant of the known form.

We propose that articulatory units differ in how much they are subject to perseveration. These differences in *perseverance* (susceptibility to perseveration) act as biases, causing learners to level stem changes that involve changing a unit that is highly susceptible to perseveration.[2] Further, the greater the articulatory difference between the known form and the to-be-produced form, the more likely the change is to fail, or at least be carried out incompletely, since every one of the articulatory units present in the known form can (erroneously) persevere. Note that this is not a bias against *all* uncommon changes. Some changes may be uncommon for perceptual reasons, but we do not have any evidence to suggest that perceptual magnitude of a change influences its learnability (cf. Steriade, 2001 for a suggestion that it does). There is one published study that examined the relationship between change naturalness and learnability, and failed to find one: Wilson (2006) observed that [k]-->[tʃ] and [g]-->[dʒ] did not differ in learnability despite [ki] and [tʃi] being more perceptually confusable than [gi] and [dʒi] (Guion, 1998). The present hypothesis is consistent with this finding: [k] and [g] differ only in voicing, which is not changed in palatalization and is articulatorily independent from the rest of the features of [k] and [g]; thus, the perseveration hypothesis predicts no learnability difference between [k]→[tʃ] and [g]→[dʒ].

Formally, the proposed bias is equivalent to a ranking of output-output faithfulness constraints (Kenstowicz, 1996) in Optimality Theory or unequal weighting in Harmonic Grammar (Smolensky & Legendre, 2006). Namely, we will show that changing [k] or [t] into [tʃ] is easier than changing [p]. In Optimality Theory / Harmonic Grammar, this could be described with a ranking: ("Keep [k]", "Keep [t]") << "Keep [p]". One way to model what subjects are learning in the experiment is an increased weight on a constraint saying that to-be-produced plural forms should end in [tʃi]. As the weight of this constraint rises, it overtakes "Keep [k]" and "Keep [t]" before overtaking "Keep [p]". As a result, palatalization overgeneralizes from [p] to [t] and [k].

Faithfulness constraints are not a new idea in linguistics. What is new here is the claim that the faithfulness constraints in question are production-internal perseveratory tendencies specific to articulatory units. One appealing consequence of this proposal is that it provides a unified explanation for the bias to add rather than delete noted in both work on speech errors (Goldstein et al., 2007; Hartsuiker, 2002; Stemberger, 1990) and work on loanword adaptation in phonology (Kang, 2011; Paradis & LaCharité, 1997). In both cases, articulatory units are clamoring for retention but nothing clamors for deletion, unless there are strong prosodic constraints limiting word or syllable shape (the only case when exceptions to the addition bias are found in loanword adaptation, according to Kang, 2011). The proposal that faithfulness constraints are rooted in perseveration explains this typological generalization. Making the relatively uncontroversial assumption of the existence of morphological units in speech production (e.g., Dell, 1986; Roelofs, 1997), the proposed perseveration can also straightforwardly capture the tendency for insertions to happen at morpheme or stem boundaries rather than morpheme- or stem-internally (Kenstowicz, 1994): perseverating on a morphological/lexical unit prevents changes inside that unit.

We propose that the bias against (certain) stem changes is internal to the production system. We therefore expect that it will manifest itself more strongly in production than in acceptability rating. This prediction is consistent with previous findings that a form with a stem change can be judged as being more acceptable than a form without a stem change and yet be less likely to be produced (Kapatsinski, 2012; Zuraw, 2000). Perseveration/self-priming is also commonly observed in elicited production tests of rule productivity, where participants have been observed to repeatedly reuse a phoneme sequence in novel words elicited on adjacent trials, even when the result violates normal paradigmatic mappings or affix order preferences (Bickel et al., 2007; Lobben, 1991).

Finally, the idea that output-output faithfulness is rooted in motor perseveration is consistent with data from language acquisition and motor development and provides an independent justification for the initial high ranking of such constraints proposed to be necessary to make Optimality-Theoretic grammars learnable (Hayes, 2004; McCarthy, 1998). Children are known to exhibit more motor perseveration than adults (e.g., Smith et al., 1999; including perseveration on phonetic segments: Stemberger, 1989; Vousden & Maylor, 2006). It is therefore unsurprising that they would perseverate more on a known form while deriving an unknown morphologically-related form (e.g., Do, 2013), the pattern predicted by a high initial ranking of OO-Faithfulness ("keep the X from the base form") constraints. In fact, perseveration on inflectional morphemes recently produced (by children or their interlocutors), a perseveratory tendency present but greatly diminished in

[2] The differences in perseverance may be universal, rooted in early articulatory experience, or language-specific. Further, universal differences may be reduced or augmented by linguistic experience. We do not seek to determine the source of the observed bias in the present paper. Our aim is simply to demonstrate that biases of the proposed form exist.

adults, has been noted in the language acquisition literature where perseveration on interlocutors' wordforms has been argued to be functional in that the repeated morpheme is usually correct in the context of the child's own utterance (Ambridge & Lieven 2011:164-65). Again, it is only when it is incorrect that we notice the perseveration; most of the time perseveration is correct and perseverating on the known form is a good strategy.

Predictions

The present experiments focus on a particular phonological alternation, called palatalization, where a word-final [p], [k] or [t] alternates with [tʃ] when followed by [a] but is left unchanged before [i]. This is a pattern that runs counter to phonetic naturalness (Guion, 1998; Kochetov, 2011; Mitrovic, 2012; Wilson, 2006) but is attested in some languages, e.g., before Russian diminutives, where –ok palatalizes preceding [k] more than –ik does (Kapatsinski, 2010). Velar palatalization (k→tʃ) and alveolar palatalization (t→tʃ) are much more common than labial palatalization (p→tʃ) (Kochetov, 2011) and involve an articulatorily more minor change, since [t], [k] and [tʃ] are all lingual gestures, while [p] is a labial one. Velar and alveolar palatalization are attested approximately equally often in languages of the world (Kochetov, 2011) and [tʃ] shares articulatory characteristics with both [t] and [k], involving both tongue tip (like [t]) and tongue body (like [k]) gestures (Yun, 2006). The present experiment thus seeks to determine whether there is a bias against the less natural alternation (p→tʃ) even in a context where *no* palatalizing alternation is particularly natural (before [a]).

An important, and counterintuitive, prediction of the theory is that the bias against changing a unit should be context-independent, to the extent that the unit in question is independent of the context in question in motor planning and execution. The articulatory unit addressed by the present experiments is the oral consonantal gesture. Work on speech errors suggests that consonants, and especially onsets, can move around in the motor plan independently from vowels (e.g., Fowler, 2010; Meyer, 1992, p. 185-86; Shattuck-Hufnagel, 1983).[3]

Our previous work (Kapatsinski 2012b) has demonstrated that labial palatalization is more difficult to acquire than velar or alveolar palatalization in the context of a following [i], i.e., in a context where velar or alveolar palatalization are phonetically motivated. However, this result is consistent with a bias in favor of natural *rules*, i.e., changes in context. However, if [p] is harder to change into [tʃ] than [k] or [t] are independently of context, this should be true even if the vowel triggering palatalization is [a]. This prediction is tested in the experiment reported here.

[3] There is some argument regarding whether the 'segmental' errors typically involve segments (Roelofs 1999, Stemberger 1982) or gestures (Goldstein et al. 2007, Mowrey & MacKay 1990). The distinction is unimportant for the present purposes: the vocalic context is outside of both the segment and the gesture.

Methods

The grammars presented to learners are shown in Table 1. There were three groups of participants. The Velar Group was presented with a language in which [k] became [tʃ] before [a] while [p] and [t] remained unchanged, e.g., [bik-bitʃa, bit-bita, bip-bipa]. The Labial Group was presented with a language in which [p] became [tʃ] before [a] while [k] and [t] remained unchanged. The Alveolar Group was presented with a language in which [t] became [tʃ] [a] while [k] and [p] remained unchanged. In all languages, [i] and [a] were plural suffixes. In all languages, the palatalizing consonant was twice as common as any one of the non-palatalizing ones.

Table 1: Grammars presented to learners. A separate group of subjects was assigned to learn each of the languages below.

Velar Group:	Alveolar Group:	Labial Group:
ik→itʃa	it→itʃa	ip→itʃa
ak→{aki;atʃa}	at→{ati;atʃa}	ap→{api;atʃa}
t→ta	k→ka	k→ka
p→pa	p→pa	t→ta

Languages were created from each other by swapping final consonants in the singulars, meaning the contexts surrounding the palatalized consonants were exactly parallel across the three groups within each experiment. The stimuli were then recorded by the first author and presented to participants, all adult native English speakers recruited from the Psychology/Linguistics human subjects pool, auditorily through headphones. There were 25 participants in the Alveolar Group, 29 in the Labial Group and 30 in the Velar Group. All words were paired with pictures of referents presented on the screen and presented in totally random order. Participants were asked to learn the names of the referents. A third of the way through training, they were tested on word learning by being asked to produce all wordforms they were presented with in the training when cued with pictures of the referents. At the end of training, the participants encountered an elicited production test, where they were presented with novel singular forms (which they had not encountered during training) and were asked to say the right plural form. The production test was followed by a rating test, in which the participants were presented with novel singular-plural pairs and were asked to press a button indicating whether the presented plural form was the right one for the presented singular. Statistical significance was evaluated using the original binary responses by means of logistic mixed effects models in the lme4 package in R (Bates et al., 2012) with random intercepts for subjects and items and random slopes for between-subject variables within Item and between-item variables within Subject (following Barr et al., in press). All analyses reported here were done on trials where –a was the suffix vowel chosen or presented.

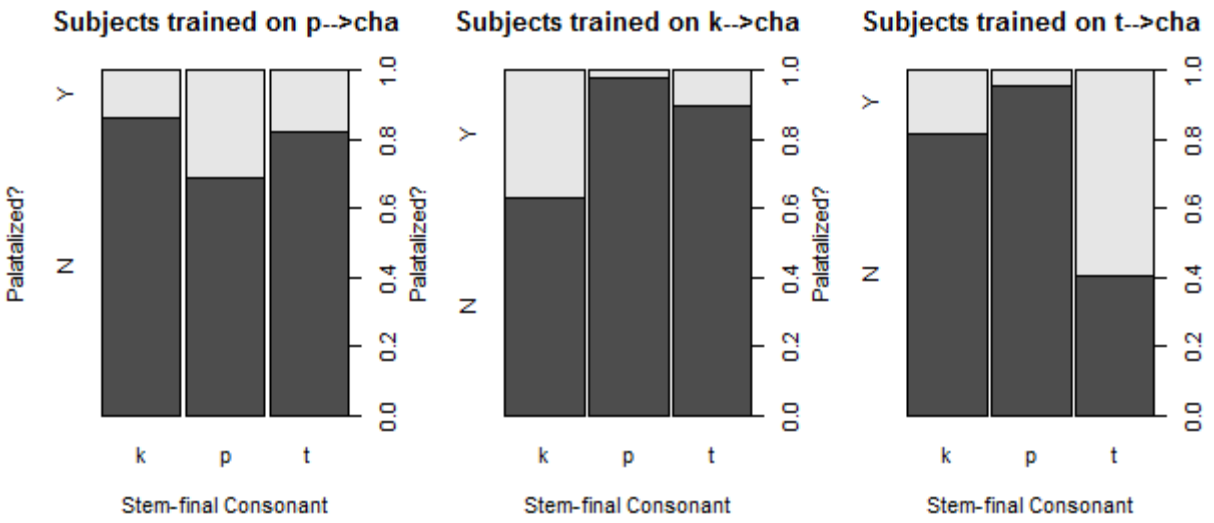

Figure 1: Results of the elicited production test. Vertical axes show whether or not the consonant was palatalized (Y, shown in light, is "palatalized", N, shown in dark, is "not palatalized"). Participants exposed to labial palatalization before [a] palatalize [t] and [k] almost as much as they palatalize [p] (though the difference is significant: z=3.02,p=.002 for [p] vs. [k] rates and z=2.85, p=.004 for [p] vs. [t]). Participants exposed to alveolar palatalization palatalize [t] much more than other stops (z=5.87, p<.00001 for [t] vs. [k]; z=10.57, p<.00001 for [t] vs. [p]). [p] is palatalized less than [k] (z=3.35, p=.0008). Participants exposed to velar palatalization palatalize [k] more than [p] (z=10.00,p<.00001) and more than [t] (z=5.16, p<.00001); [t] is palatalized more than [p] (z=8.55,p<.00001).

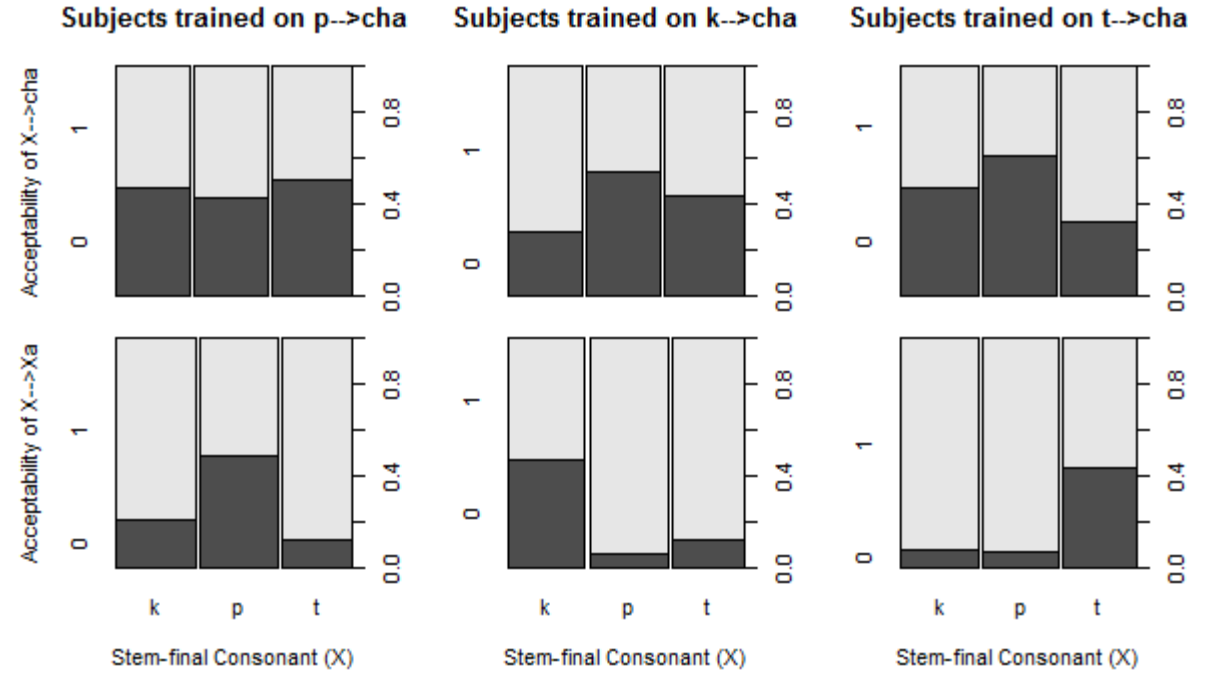

Figure 2: Results of acceptability judgments in Experiment 2. Dark parts of bars show the proportion of 'this is the wrong plural form for this singular' responses. Light parts of bars show the proportion of 'this is the right plural form for this singular' responses. Following training on labial palatalization, subjects accept palatalized labials (p→tʃa), alveolars (t→tʃa) and velars (k→tʃa) at roughly equal rates whereas following training on alveolar or velar palatalization, the trained alternation is accepted more often than untrained ones. However, after all kinds of training subjects learn to reject unchanged/non-palatalized stops before the palatalizing vowel [a], and they do it at equal rates.

Results

As shown in Figure 1, participants exposed to labial palatalization do not learn the pattern as well as participants exposed to velar or alveolar palatalization do, often learning to palatalize everything or to palatalize nothing. The differences in palatalization rates between the to-be-palatalized consonant and the not-to-be-palatalized consonants is significantly smaller in the group trained on p→tʃ than in the group trained on k→tʃ ($z=8.98$, $p<.00001$) or t→tʃ ($z=3.34$, $p=.0008$); the latter two groups do not significantly differ ($z=0.09$, $p=.93$).

Figure 2 suggests that the same pattern holds for acceptability judgment data: subjects trained on p→tʃa judge p→tʃa examples ungrammatical almost as often as examples of t→tʃa and k→tʃa (for this group, there is no significant effect of singular-final consonant on acceptability of palatalization, $z=0.76$, $p=.45$). By contrast, subjects trained on t→tʃa or k→tʃa judge the alternations they were trained on as being grammatical more often than alternations they were not trained on ($z=2.84$, $p=.004$).

In addition, Figure 2 shows that the bias against labial palatalization (i.e., changing [p] into [tʃa] rather than [pa]) is not due to a bias in favor of [pa]: subjects learn that [a] should not be preceded by [p] as easily as they learn that it should not be preceded by [k] ot [t]: while p→tʃ is worse than k→tʃ and t→tʃ, [pa] is as bad as [ka] and [ta] ($z=.83$, $p=.39$). Thus the observed bias against p→tʃ is not a bias in favor of [pa] or against [ka] and [ta].[4]

Finally, stem changes are accepted in acceptability judgment much more than they are produced: the dark bars in Figure 2 are lower than in the top panels of Figure 1 ($z=3.07$, $p=.002$), indicating that palatalization is usually rated as acceptable, and in fact more acceptable than non-palatalization, yet is rarely produced. Furthermore, the bias against labial palatalization appears to be stronger in production than in judging acceptability: to-be-palatalized and not-to-be-palatalized consonants differ in acceptability of palatalization across subject groups numerically but not significantly ($z=1.11$, $p=.27$), but, as described above, these between-group differences are significant in production. The three-way interaction between test modality, whether or not a consonant is to be palatalized, and subject group is also significant ($z=2.37$, $p=.018$). These data provide direct evidence for a production basis for faithfulness and the observed bias against p→tʃ.

[4] Some may wonder whether participants actually learn to palatalize before [a] rather than learning to palatalize before [i] or after [i]. There was no effect of stem vowel on acceptability ($z=1.01$, $p=.31$) of palatalization, whereas in production stem [i] *dis*favored palatalization ($z=3.55$, $p=.0003$) rather than favoring it. The effect of final vowel on palatalization production probability ($z=4.99$, $p<.00001$) and acceptability ($z=2.14$, $p=.03$) was in the direction predicted by training, rather than phonetic naturalness, i.e., palatalization occurred/was rated more acceptable than non-palatalization before [a] more often than before [i]. Thus, the vowel triggering palatalization in the grammars learned by our subjects does appear to be a following [a], making the context for palatalization phonetically unnatural.

Discussion and Conclusion

In this experiment, we have demonstrated that there is a bias against labial palatalization in a context where all kinds of palatalization are phonetically unmotivated. Thus we suggest that the bias is not in favor of phonetically-motivated rules, or changes in context. We have also shown that the bias is not due to differentially ranked phonotactic constraints on the output forms: the result of alternation is always the same [tʃa], regardless of the consonant that is changed, and learners acquire a dispreference against [pa], [ta], and [ka], the outputs competing with [tʃa] equally well. We are therefore left with two options, both of which can be modeled using Faithfulness constraints in Harmonic Grammar (Smolensky & Legendre, 2006): the learners might be biased against mapping [p] onto [tʃ] (Steriade, 2001), or against deleting the labial closure gesture associated with [p] (Kapatsinski, 2013; Kenstowicz 1996).

Theories of Faithfulness / avoidance of stem changes differ on whether Faithfulness is grounded in perception (avoiding changes that the listener would easily perceive and would face difficulty undoing to recover the base form of the stem, Steriade, 2001), articulation (perseverating on gestures of the known form while deriving an unknown form, Kapatsinski, 2013), or an offline preference for uniform morphological paradigms (e.g., storage economy or one-to-one form-meaning mappings, Kenstowicz's [1996] uniform exponence; McCarthy's [2005] optimal paradigms). The present data support the gestural account, as it alone seems to account for the differences between production and acceptability judgment. Namely, the biases against stem changes are stronger in production (see also Kapatsinski, 2012; Zuraw, 2000). The gestural account is also the only one that can account for the data described in the introduction, and it alone seems to be an inevitable component of the production process when a novel form is derived from a known one.

The bias we observe may or may not be specific to English speakers. While labials are unlikely to change across languages (e.g., Kochetov, 2011), English does have palatalization of alveolars, as in *create*/*creature* or, variably, in *would*/*would you*. The fact that we also observe a preference for velar palatalization over labial palatalization suggests that the preference against labial palatalization is not solely a first-language effect. Nonetheless, first language experience undoubtedly changes the weights of faithfulness constraints, hence cross-linguistic and developmental work on this issue would be most informative. Of particular interest here are languages that have labial palatalization, e.g., Southern Bantu (Ohala, 1978).

All we wish to claim at this point is that there *are* faithfulness constraints militating against stem changes, regardless of context, that they are production-based, and that they vary in weight, making some of these constraints stronger than others at the beginning of our experiment.

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