# Directionality of assimilation in consonant clusters: An experimental approach

Anne Pycha, Eurie Shin, and Ryan Shosted

University of California, Berkeley
Department of Linguistics
1203 Dwinelle Hall
Berkeley, CA 94720-2650
pycha@berkeley.edu, eurie@berkeley.edu, shosted@berkeley.edu

## 1. Introduction

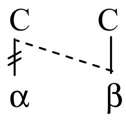
The goal of the current study is to test the learnability of three different place assimilation patterns, as schematized below:

- Regressive place assimilation
  $VC_1C_2V \rightarrow VC_2C_2V$
- Progressive place assimilation
  $VC_1C_2V \rightarrow VC_1C_1V$
- Arbitrary place assimilation
  Regressive for some clusters, progressive for others

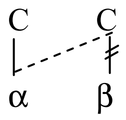
These patterns can be distinguished along two dimensions. The first dimension concerns perceptual naturalness. The regressive pattern, in which the place features of the second consonant "win" the assimilation, can be referred to as perceptually natural because the place cues for a consonant are perceptually enhanced in a pre-vocalic position ($C_2$) yet relatively diminished in post-vocalic, pre-consonantal position ($C_1$) (Fujimura et al. 1978, Ohala 1990, Jun 1995). The progressive pattern, in which the place features of the first consonant win, can be referred to as perceptually unnatural for the same reasons.

The second dimension concerns formal simplicity. We can capture both regressive and progressive assimilation rules with the same formal statement, regardless of the theoretical framework used. For example, in autosegmental phonology, both types of assimilation consist of the delinking of one association line followed by the spreading of another. The only difference between the two processes lies in directionality: i.e., do we get delinking followed by leftward spreading, or rightward spreading?

1) a. Regressive assimilation



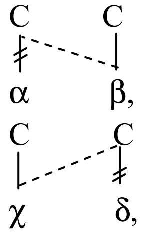
b. Progressive assimilation



Thus regressive and progressive assimilations possess equivalent formal simplicity, despite their differences in perceptual naturalness.

An "arbitrary" assimilation pattern, however, is more formally complex. In an arbitrary system, regressive assimilation occurs for some clusters, but progressive occurs for others. Thus the input-output mapping for each cluster must be represented separately, requiring multiple formal rules for a single pattern.

2) Arbitrary assimilation



etc.

The differences between perceptually natural and unnatural processes on the one hand, and formally simple and complex processes on the other, play important roles in phonology but the proper characterization of these roles has been the topic of debate. Steriade (2001), for example, has argued that perceptual naturalness plays a synchronic role. Her perceptual-mapping, or P-map, hypothesis claims that a speaker's grammar actively calculates the changes in perceptibility that an alternation brings about: "[t]he likelihood that a lexical representation R will be realized as modified R' is a function of the perceived similarity between R and R' " (2001: 222). Others have argued that perceptual factors play a role only in diachronic change, not in synchronic processing (Blevins 2004; see also Blevins & Garrett 1998, Barnes 2002, Yu 2004).

The debate over the proper role of perceptual factors motivated the current laboratory study, in which we exposed naive listeners to nonce languages with assimilation patterns that differed in both perceptual naturalness and/or formal complexity. We evaluated two null hypotheses: in short-term learning of a novel assimilation pattern, subjects will perform no differently when 1) learning a natural vs. unnatural rule, or 2) learning a simple vs. complex rule.

If P-map is correct, perceptibility should affect the learnability of a novel alternation after brief exposure. Alternations in which the difference between the lexical and surface representations is less perceptible should be better learned, because the perceptibility calculation forms part of the listener's grammatical bias. Thus for the place assimilation patterns discussed above, P-map predicts that regressive place assimilation should be better learned. That is, since the perceptibility of $C_2$ place exceeds that of $C_1$ place in the lexical representation /$VC_1C_2V$/, the mapping to an output form that preserves $C_2$ place while changing $C_1$ place [$VC_2C_2V$] is preferred.

In what follows, we briefly survey previous research on perceptual factors in phonology, and situate laboratory learning within this research (§2). We describe the methodology we used to test the learnability of assimilation patterns (§3) and the results we found (§4). Our study revealed no significant difference in the learnability of natural versus unnatural patterns, although it revealed a significant difference in the learnability of formally simple versus complex ones. Our results are thus in agreement with some, but not all, previous laboratory studies that have examined this issue. We conclude with a discussion of methodological questions that arise in such studies and outline our goals for future research (§5).

## 2. Previous work on perceptual factors in phonology

There is general agreement that perceptual factors play some kind of explanatory role in sound patterns, but disagreement as to whether this role is best characterized as a synchronic or diachronic one. For the place assimilation patterns under discussion here, Steriade (2001) and others have argued for a synchronic role. The basic idea, as described above, is that the regressive tendency found cross-linguistically is due to the fact that speakers somehow know that $C_2$ is more perceptible than $C_1$. Other linguists, notably Blevins (2004), have argued for a diachronic role. Here the basic idea is that the diminished cues for $C_1$ place make it prone to misperception in the $VC_1C_2V$ context; if listeners interpret their misperceptions as part of the grammar, this can give rise to alternations in the next generation of speakers.

A number of studies, using a wide range of methodologies and argumentation, have touched on this debate. Synchronic studies, for example, have examined the positional licensing of certain features. Steriade (1997) argues that the distribution of retroflexion in Gujarati and ejective consonants in Klamath can only be described with reference to "cue-rich" positions; that is, these features are contrastive just in those positions where they are perceptually most salient. Gerfen (2001), however, argues that coda neutralization in East Andalusian Spanish requires reference to the syllable as traditionally conceived, and cannot be analyzed using cue-rich positions. A number of historical studies have followed a somewhat different tactic, drawing a distinction between the across-the-board changes in perceptibility invoked by the P-map hypothesis and the specific types of perceptions (or misperceptions) that are likely to occur in certain positions. Studies conducted in this vein include Blevins & Garrett (1998) on consonant-vowel metathesis, Barnes (2002) on vowel neutralization, Yu (2004) on coda voicing, and Blevins (2004) on gemination and other patterns, all of whom argue for the diachronic role of perceptual factors.

Both synchronic and historical studies must acknowledge that speakers can and do learn perceptually unnatural patterns, such as the progressive place assimilation in Noni, /ciing-te/→ [ciing-kè] 'be trembling' (Larry Hyman, p.c.). The common goal of loanword and laboratory studies is to examine the behavior of listeners and speakers outside the context of these learned patterns to determine if any universal tendencies are operative. Loanword studies, for example, examine changes that novel segments or segment combinations undergo when they enter a language. Kawahara's (2006) study of voiced geminates in Japanese, as well as Fleischhacker's (2002) and Zuraw's (2005) studies of consonant cluster splitting, all argue for the synchronic role of perceptual factors in loanword adaptation.

Laboratory studies also test for the presence of universal tendencies outside the context of language-specific patterns. Yet unlike loanword studies, which are necessarily limited by the inventory of loans in a particular language and complicated by the entrance of loans into the language during different periods of time, laboratory studies present listeners and speakers with novel patterns that can be controlled by the investigator. While this approach lacks the organic quality of language learning in context, it nevertheless presents significant advantages as a way to probe the role of perceptual factors in language: the investigator can isolate a single perceptual factor and manipulate that factor only.

Studies conducted in this vein have tested both infants and adults. For both populations, the results are mixed. At least one set of infant studies has concluded that infants seem to prefer new patterns that are perceptually natural (Jusczyk et al. 2002) but a follow-up study by the same researchers found no such effect (Jusczyk et al. 2003). Seidl & Buckley (2005) also found no preference for perceptually natural patterns in infants. For adults, studies by Wilson (2003) and Peperkamp et al. (in press) found an effect of naturalness but those of Pycha et al. (2003) and Peperkamp & Dupoux (in press) did not. Most recently, Wilson (2006) has argued that perceptual naturalness operates as a violable bias in the learning of velar palatalization alternations[1].

It is important to note that these studies do not all examine the same phonological alternations, nor do they all use the same definition of naturalness. For example, Peperkamp et al. (in press) invoke phonetic proximity, contextual relevance, and markedness reduction as three factors that contribute to what they call "phonetic naturalness". All of these certainly play an important role in phonology, but none of them distinguishes between regressive versus progressive direction in assimilation: both are operations in which a small set of features (phonetic proximity) spread from trigger to target (contextual relevance) to produce a surface form that is unmarked (markedness reduction). Our study thus focuses specifically on the definition of perceptual naturalness invoked by Steriade (2001) and as a result, we engage most directly with two aforementioned studies that also incorporate this definition: Wilson's (2006) study of adults learning velar palatalization patterns and Juszcyk et al.'s (2003) study of infants exposed to consonant place assimilation patterns.

## 3. Methods

To test whether a) perceptual naturalness and b) formal complexity impact the learnability of novel patterns, we constructed three nonce languages. All three consist of CVC nonce roots, and a total reduplication construction in which a root can be combined with itself. For example, the nonce languages each contain a nonce root /kut/. This root can be combined with itself in total reduplication, /kut-kut/, a construction that is quite similar to the emphatic reduplication commonly used in American English ("Was that a toy cat or a *cat* cat?").

The three languages differ minimally in their phonological behavior. The consonant clusters created by the total reduplication construction undergo place assimilation, but the languages differ in the directionality of assimilation.

3)

| | |
|---|---|
| Regressive language | /kut-kut/ → /kukkut/ |
| Progressive language | /kut-kut/ → /kuttut/ |
| Arbitrary language | /kut-kut/ → /kukkut/ |
| | /kup-kup/ → /kuppup/ |

In the Regressive language, the /tk/ cluster created by the total reduplication of /kut/ undergoes regressive assimilation and surfaces as [kk]. Other clusters created by other

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[1] Earlier studies that used laboratory learning to examine phonological patterns include Schane et al. (1975) and Healy & Levitt (1980).

roots behave similarly (/kt/ → [tt], /pt/ → [tt], /tp/ → [pp], and so on). In the Progressive language, the /tk/ cluster undergoes progressive assimilation and surfaces as [tt]; again, other clusters behave similarly. In the Arbitrary language, some clusters undergo regressive assimilation while others undergo progressive assimilation. The set of clusters that undergo assimilation in a particular direction cannot be learned on the basis of place or voicing; each input-output mapping must be learned individually. Thus the Regressive and Progressive languages differ in perceptual naturalness, and both of these languages differ from the Arbitrary language in formal complexity.

The use of total root reduplication crucially avoids problems that might be introduced by root-affix constructions. It is well known that phonological material in roots is often preferentially preserved over material in affixes. Because both elements of the total reduplication construction are roots, and the roots are identical, they should be subject to exactly the same faithfulness constraints. We can therefore eliminate root faithfulness as a factor in the learnability of our nonce grammars, and manipulate directionality exclusively.

For each language, the stimuli included both CVC roots and CVC-CVC reduplicated forms. The roots were created with the following twelve shapes: /kVt, kVp, tVp, tVk, pVt, pVk, gVd, gVb, dVb, dVg, bVd, bVg/. The five vowels /i, ɛ, a, o, u/ were combined with these shapes to produce sixty roots. To create the root stimuli, each root was produced by a male native speaker of Polish, recorded and digitized.

Creation of the reduplicated forms was somewhat more complicated, because we wanted to avoid the problems that might be introduced by stress placement in polysyllabic forms. Just as roots can behave differently than affixes, stressed syllables can behave differently than unstressed ones. To eliminate stress as a factor, we did the following. The same male native speaker of Polish recorded a surface reduplicant form. For example, in the Regressive language, /gad-gad/ → [gaggad]. Therefore, the speaker produced [gaggad], without worrying overly much about stress placement. The closure of the medial [gg] was excised, and the final stimulus [gaggad] was produced by combining a recording of the monosyllable [gag], followed by the [gg] closure, followed by a recording of the monosyllable [gad]. This method is based on the assumption that the speaker produced all monosyllables with equal stress, and is therefore not fool-proof, but it provided a reasonably efficient means of creating disyllables with roughly equivalent loudness and pitch on each syllable.

Each stimulus consisted of a root followed by a reduplicated form. In the Regressive language, for example, one grammatically correct stimulus consisted of "*gad...gaggad*". In the Progressive language, the analogous trial consisted of "*gad...gaddad*". And in the Arbitrary language, one trial was *"gad...gaddad*" while another was *"gab...gabbab.*"

Subjects were informed they were listening to emphatic reduplication in another language, and were instructed explicitly to learn the pattern. Trials were played in three phases. The exposure phase consisted of ten trials to which subjects listened, but did not respond. Each trial was grammatically correct for the language in question; thus subjects learning the Regressive language heard only regressive patterns, and so on. The supervised learning phase consisted of twenty stimuli, each repeated twice (20 x 2 = 40 trials). For each language, half of the trials were grammatical but half were not. For example, in the Regressive language, *kut...kukkut* is a grammatical trial but *kut...kuttut* is not. Subjects were instructed to make a grammaticality judgment by pressing a Correct button or an Incorrect button. They received feedback for each response. Finally, the testing phase consisted of thirty novel stimuli, each repeated twice (20 x 3 = 60 trials). Again for each language, half of the trials were grammatical but half were not, and subjects were instructed to make a grammaticality judgment. During this phase, however, subjects received no feedback about their judgments.

Subjects were 32 adults, all native speakers of American English, who were paid for their time. Thirty of these subjects were randomly assigned to one of the three languages (Regressive, Progressive, Arbitrary). Two of these subjects experienced technical problems during the experiment, and so their results were discarded and replaced with those of two new subjects. The two new subjects were assigned to same groups as those of the subjects whose results had been discarded.

In order to properly evaluate our hypothesis, it is important that we know whether the subjects can, in fact, perceive a difference between an unassimilated input form such as /kut-kut/ and an assimilated output form such as [kukkut]. Therefore, all subjects participated in a discrimination task in which they made same-different judgments for auditory nonce words with heterorganic clusters (such as *akpa*) and minimally different words with geminate sequences (such as *appa).* It is also important for us to know whether subjects in the three groups exhibit differences in their general language-learning strategies and capacities; such differences have been documented in a number of previous studies (see e.g. Beddor & Gottfried 1995). Therefore, all subjects participated in a task in which they were asked to learn a syllable-based alternation that crucially does not depend on perceptibility factors of the kind being tested here.

The main experiment lasted approximately thirty minutes, the pattern learning task approximately fifteen minutes, and the discrimination task approximately ten minutes. Thus each subject participated for about one hour in total.

A caveat in regards to our subject population is that coronals can undergo regressive place assimilation in fast American English speech. The assimilated form is in free variation with reduction to glottal stop; thus *fat cat* can be pronounced *fa[ʔk]at* or *fa[kk]at.* The process can occur in compounds: *suitcase* can be pronounced *sui[ʔk]ase* or *sui[kk]ase*. But assimilation does not occur in emphatic reduplication (*cat cat* cannot be pronounced *ca[kk]at*) nor does it affect segments other than coronals (*snack time* cannot be pronounced *sna[tt]ime*), so it differs in significant ways from the patterns under discussion here.

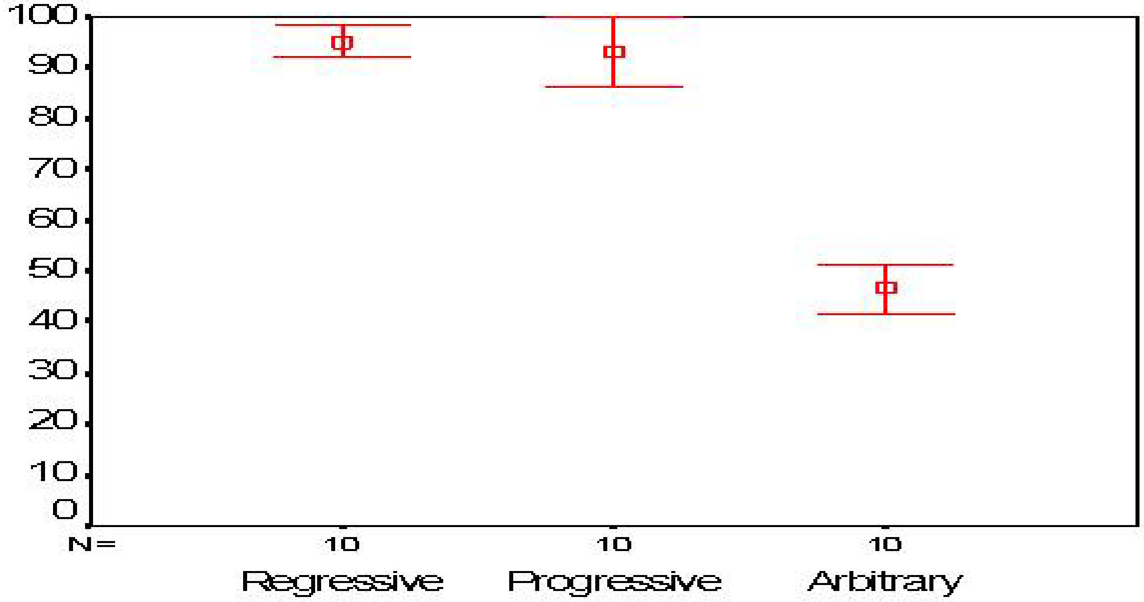
## 4. Results

Results for the main experiment are based upon the percent correct score that each subject achieved during the testing phase, and are shown in the table and figure below.

*Table 1. Learning of consonant place assimilation patterns*

| | Regressive | Progressive | Arbitrary |
|---|---|---|---|
| Mean (percent correct) | 94.9 | 93.0 | 46.7 |
| SD | 4.3 | 9.6 | 6.9 |

*Figure 1. Learning of consonant place assimilation patterns*



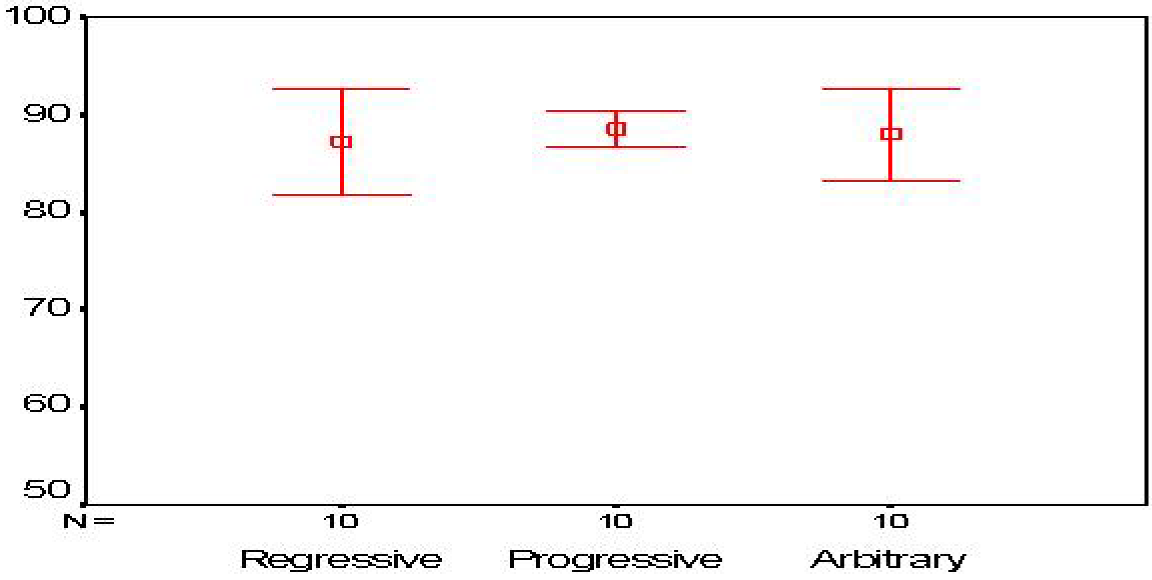
The distribution of scores was non-normal according to Shapiro-Wilk (W = 0.7743, $p < 0.001$). A Kruskal-Wallis test indicated that the scores of subjects in the three groups differs significantly (X2 (2) = 19.52, $p < 0.001$). A one-way analysis of variance confirms this result (F(1, 28) = 69.12, $p < 0.001$). A Wilcoxon Rank-Sum (Mann-Whitney U) test found no significant differences between the scores of subjects in the Regressive and Progressive groups (W = 45.5, $p > 0.5$), but significant differences between the Regressive and Arbitrary groups (W = 100, $p < 0.001$) and between the Progressive and Arbitrary groups (W = 100, $p < 0.001$).

Results for the cluster versus geminate discrimination task are also based on percent correct scores, shown in the table and figure below.

*Table 2. Discrimination of clusters versus geminate sequences*

| | Regressive | Progressive | Arbitrary |
|---|---|---|---|
| Mean (percent correct) | 87.1 | 88.5 | 87.0 |
| SD | 7.5 | 2.6 | 6.5 |

*Figure 2. Discrimination of clusters versus geminate sequences*



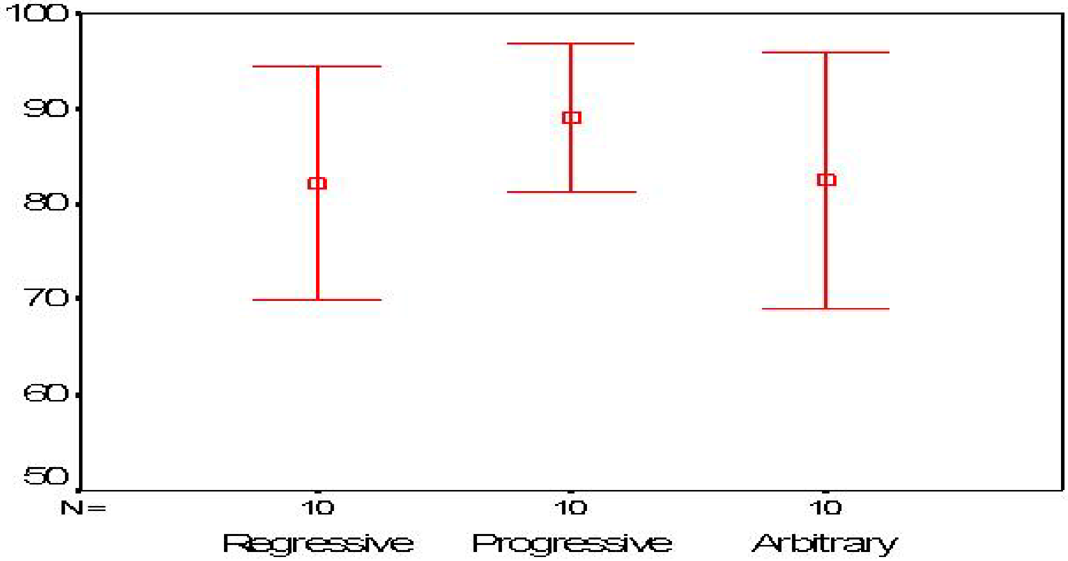
A Kruskal-Wallis test revealed no significant differences between the three groups on the discrimination task (X2 (2) = 0.13, p > 0.05). Wilcoxon Rank-Sum tests found no significant differences between the Regressive and Progressive groups (W = 52, p > 0.05), Progressive and Arbitrary groups (W = 44, p > 0.05), or Regressive and Arbitrary groups (W = 50, p > 0.05).

Results for the general language-learning task (syllable-based alternations) are also based on percent correct scores, shown in the table and figure below.

*Table 3. Learning of syllable-based alternations*

| | Regressive | Progressive | Arbitrary |
|---|---|---|---|
| Mean (percent correct) | 82.1 | 89.0 | 81.4 |
| SD | 17.0 | 10.8 | 18.7 |

*Figure 3. Learning of syllable-based alternations*



A Kruskal-Wallis test revealed no significant differences between the three groups on the syllable-based alternation task (X2 (2) = 1.31, $p > 0.05$). Wilcoxon Rank-Sum tests found no significant differences between the Regressive and Progressive groups ($W = 35$, $p > 0.05$), Progressive and Arbitrary groups ($W = 54.5$, $p > 0.05$), or Regressive and Arbitrary groups ($W = 40.5$, $p > 0.05$).

The results thus rejected the null hypothesis for formal complexity, but not for perceptual naturalness. That is, a significant difference in learning was found between subjects exposed to the Arbitrary language, which exhibits formal complexity, versus either the Regressive or Progressive languages, which does not. By contrast, no significant difference in learning was found between subjects exposed to the Regressive language, which exhibits perceptual naturalness, versus the Progressive language, which does not.

Furthermore, the results from the main experiment cannot be attributed to significant differences in the subject population. Subjects in all three groups exhibited comparable performance in discriminating between heterorganic consonant clusters and geminate sequences, and in learning a linguistic pattern unrelated to the primary pattern under investigation.

The results reported thus far are rather broad. It is still possible that a more fine-grained analysis of the results could reveal some effect of perceptual naturalness. If, for example, clusters in which [p] and [b] “win” the assimilation are easiest to learn regardless of directionality, then one might argue that the perceptual salience of labials in relation to alveolars and velars plays a role in short-term learning and thus a direct, synchronic role in phonological grammars.

To probe this question, we conducted a series of post-hoc analyses. First, we examined the error rate between the six underlying cluster types found in the reduplicated forms of the main experiment: labial-alveolar, velar-alveolar, labial-velar, alveolar-velar, alveolar-labial, and velar-labial (represented in the graphs by P for labials, T for alveolars, and K for velars). Chi-square tests show no significant differences in error rate between the six cluster types for all three conditions: Regressive ($X^2$ (5) = 6.5738 $p > 0.05$), Progressive ($X^2$ (5) = 7.2857 $p > 0.05$), and Arbitrary ($X^2$ (5) = 1.7188 $p > 0.05$). Error rates for each cluster type are depicted in the figures below.

*Figure 4. Percent error by cluster type, Regressive condition.*

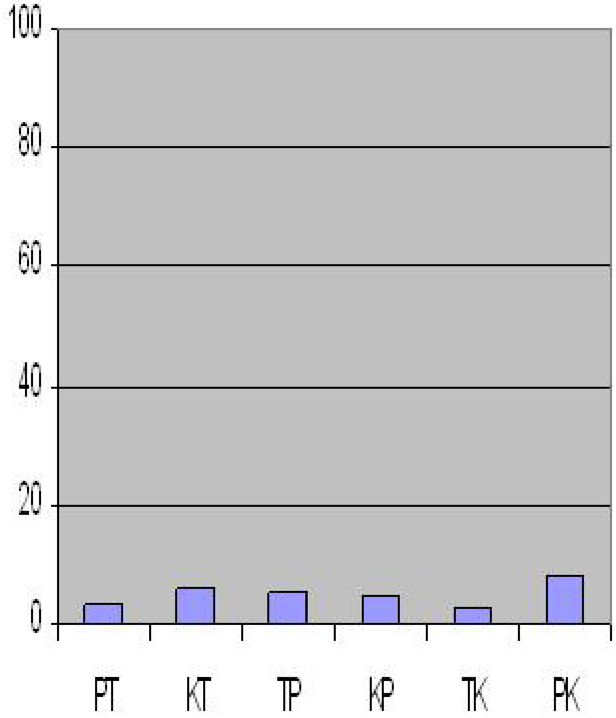


*Figure 5. Percent error by cluster type, Progressive condition.*

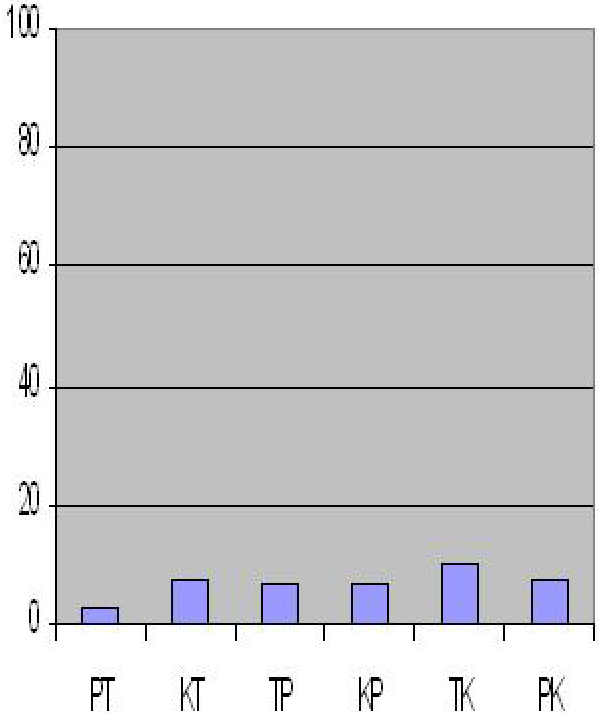
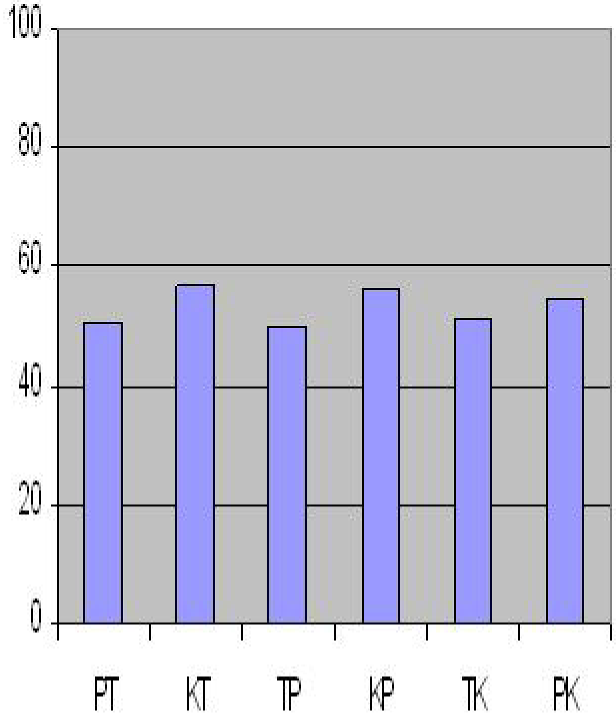


*Figure 6. Percent error by cluster type, Arbitrary condition.*



In addition to examining individual clusters, we also examined clusters on the basis of C1 place, as well as C2 place. The question of interest here is whether or not alternations in which C1 is underlyingly labial (or velar, or alveolar) are better learned than alternations in which C1 is underlyingly velar or alveolar. The same question can be asked of alternations in which C2 is underlyingly labial (or velar, or alveolar). To investigate these questions, we performed two subsequent post-hoc analyses which grouped clusters according to C1 or C2 place. Chi-square tests showed no significant differences in error rate between the three cluster types based on C1 (Regressive: $X^2$ (2) = 0.918, $p > 0.05$, Progressive: $X^2$ (2) = 3.0714, $p > 0.05$, Arbitrary: $X^2$ (2) = 0.918, $p > 0.05$) and no differences between the three cluster types based on C2 (Regressive: $X^2$ (5) = 6.5738 $p > 0.05$, Progressive: $X^2$ (5) = 7.2857 $p > 0.05$, Arbitrary: $X^2$ (5) = 1.7188 $p > 0.05$). In sum, then, post-hoc analyses do not reveal any effect of cluster type, whether we examine clusters on an individual basis or grouped by C1 or C2 place.

There is yet another way to examine the data for effects of perceptual naturalness. Our primary question is whether perceptual naturalness reveals itself in short-term learning tasks. The lack of significant difference between subjects in Regressive and Progressive conditions seemed to indicate that it does not, but another way to look at the question is within the Arbitrary condition. This language contains clusters that undergo both regressive and progressive assimilations; if speakers treat these two assimilation types differently, then perhaps those subjects who were exposed to the Arbitrary language learned regressive patterns better than progressive ones.

A chi-square test shows a significant difference in the percentage of errors made for clusters that underwent regressive assimilation versus progressive assimilation within the Arbitrary condition ($X^2$ (1) = 5.906, $p < 0.05$). The difference, however, goes in the direction opposite to that predicted by a P-map hypothesis. The error rate for regressive clusters was 56.8%, versus 49.9% for progressive clusters. Both rates are very close to chance; if anything, the higher error rate in regressive clusters seems to indicate that listeners exhibited a slight bias toward outputs with progressive assimilation.

A closer look revealed that the ten subjects in the Arbitrary condition fell into three groups, as shown in Table 4. Some subjects exhibited a bias toward progressive outputs (subjects 2, 7, 12, and 19), some toward regressive outputs (21, 22, 29), and some exhibited no evident bias (5, 8, 27).

*Table 4. Individual performances of subjects (n=10) in Arbitrary condition.*

| Subject | Regressive outputs | Progressive outputs | $X^2(1)$ | p-value |
|---|---|---|---|---|
| 2 | 15% | 76% | 43.5021 | p<0.001*** |
| 7 | 2% | 100% | 112.1645 | p<0.001*** |
| 12 | 38% | 62% | 5.6333 | p<0.05* |
| 19 | 40% | 62% | 4.8013 | p<0.05* |
| 21 | 58% | 35% | 5.6585 | p<0.05* |
| 22 | 83% | 17% | 50.7 | p<0.001*** |
| 29 | 70% | 18% | 30.414 | p<0.001*** |
| 5 | 52% | 52% | 0.0333 | p>0.05 |
| 8 | 40% | 58% | 3.3343 | p>0.05 |
| 27 | 33% | 23% | 1.026 | p>0.05 |

The results from the Arbitrary pattern seem to provide real evidence for individual differences in language learning that warrant further investigation beyond the scope of this paper. For our purposes, the important point is that inter-subject no overall difference emerged between regressive and progressive outputs, and there is thus no conclusive evidence that one directionality condition is easier to learn than the other.

## 5. Discussion

Recall the two null hypotheses under investigation here: In short-term learning of a novel assimilation pattern, subjects will perform no differently when 1) learning a natural vs. unnatural rule, or 2) earning a simple vs. complex rule.

We can reject the second null hypothesis with reasonable confidence. Subjects performed significantly better when learning a simple assimilation pattern than when learning a complex one. Formal complexity thus seems to play a tangible role in the phonological behavior of listeners, outside the context of their already-acquired patterns. This result is not particularly surprising, although the mixed behavior of subjects in the Arbitrary condition does suggest that individuals use very different learning strategies.

We cannot reject the first null hypothesis. Subjects did not perform significantly better when learning a perceptually natural pattern than when learning a perceptually unnatural pattern; they learned regressive and progressive assimilation equally well, despite the perceptual differences between these two kinds of input-output mappings.

Our results therefore do not support perceptual naturalness as a synchronic factor in phonological systems. Listeners have no apparent bias for naturalness when they are exposed to novel patterns. Just as we have not rejected the null hypothesis, however, we also have not proved it. A larger sample size is required. A power analysis predicts that in order to detect a difference between the Regressive and Progressive groups, 1302 subjects are required if we assume a small effect size (0.20), 210 subjects if a medium effect size (0.50), and 84 subjects if a large effect size (0.80).

The high percent correct scores achieved by subjects in both the Regressive (mean 94.9% [4.3]) and Progressive groups (93.0% [9.6]), however, suggests a ceiling effect. The tasks given to these two groups may have simply been too easy. Rather than adding more subjects, then, a more fruitful next step might be to degrade the conditions for perception of the auditory stimuli by introducing masking noise, or to degrade the conditions for learning by introducing a distractor task or asking subjects to make broader generalizations on the basis of the data. The current study also uses an explicit learning task, whereas an implicit learning task may do a better job of mimicking the "real-world" conditions of language learning (on implicit tasks see e.g. Wilson 2003).

In §2 we noted that the adult study of Wilson (2006) and the infant study of Jusczyk et al. (2003) invoked the same definition and predictions of perceptual naturalness used here. It is therefore instructive to examine their results in somewhat more detail, and compare them with the results reported here. Wilson (2006) studied velar palatalization patterns, in which a front vowel causes an underlying /k/ to palatalize. Confusability studies have shown that a change in which /ki/ → [či] is less perceptible than one by which /ke/ → [če]. In other words, [ki] and [či] are highly confusable with one another, while [ke] and [če] are less so. Wilson (2006) tested the impact of these perceptibility facts on learning. One group of subjects learned a nonce language in which /ke/ → [če]. This group generalized palatalization to high vowels, applying it with reasonable consistency to underlying forms containing underlying /ki/. Another group of subjects learned a nonce language in which /ki/ → [či]. This group did not, however, generalize palatalization to lower vowels, and did not consistently apply it to forms containing underlying /ke/. Wilson (2006) concluded that perceptibility factors show up in the grammar not as rock-solid rules, but as learning biases toward alternations that change percepts the least.

The infant studies of Jusczyk et al. (2003) used phonological alternations similar to those used in the current study. In one of these studies, twenty-four 4.5 month old infants were tested with the head-turn preference procedure, and exposed to triads of nonce words that in which NC sequences underwent regressive place assimilation (*an…bi…ambi*) as well as progressive place assimilation (*an…bi…andi*). They found no significant difference in infant listening time for the two assimilation types. Jusczyk et al.'s (2003) results are particularly significant because they studied directionality of assimilation, precisely the issue under investigation here, and also found no effect of naturalness, just as reported here.

These studies raise some methodological issues that deserve discussion in further detail. For example, Wilson (2006) used a method in which listeners were exposed to a particular pattern and were then free to apply this same pattern (or not) to novel data. His subjects also produced novel forms verbally; these forms were recorded, transcribed, and analyzed. This production mode contrasts with the purely perceptual modes used in the current study and in Jusczyk et al. (2003), and may contribute to the different findings. It is also possible, however, that the P-map hypothesis is valid for some phonological alternations but not for others. That is, while the findings for velar palatalization seem to support Steriade's P-map (2001) hypothesis, the findings for consonant place assimilation do not, suggesting that two very different modes of learning are operative in each case.

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