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PHONOLOGY SHAPED BY PHONETICS: THE CASE OF INTERVOCALIC LENITION

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Abby Kaplan

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The Dissertation of Abby Kaplan
is approved:

Professor Jaye Padgett, Chair

Professor Armin Mester

Professor Grant McGuire

Professor Keith Johnson

Tyrus Miller
Vice Provost and Dean of Graduate Studies

Contents

List of Figures

Abstract

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The goal of this dissertation is to explore the phonetic bases of intervocalic lenition – specifically, voicing and spirantization of intervocalic stops. A traditional understanding of phonological patterns like these is that they involve articulatory effort reduction, in that speakers substitute an easy sound for a hard one. Experiment 1 uses a novel methodology to investigate whether voiced and spirantized productions are truly easier than their unlenited counterparts: the speech of intoxicated subjects is recorded and compared with their speech while sober, on the hypothesis that intoxicated subjects expend less articulatory effort. This experiment thus attempts to observe effort reduction in action in the laboratory. The results of Experiment 1 do *not* provide evidence that voicing and spirantization are effort-reducing; rather, intoxicated subjects exhibit an overall contraction of the articulatory space. Experiments 2 – 4 investigate whether an alternative account of lenition based on perception is viable. Results suggest that attested alternations such as spirantization of voiced stops are preferred on perceptual grounds to unattested alternations such as intervocalic devoicing. Thus, the hypothesis of the P-map (Steriade 2001) can explain the broad strokes of lenition, although differences by place of articulation found in Experiment 3 do not match well with the typology. I conclude with an analysis of intervocalic spirantization couched within Optimality Theory, and particularly Dispersion Theory, using constraints motivated by Experiments 1 – 4. Unlike previous accounts of lenition, this anal-

ysis invokes no constraints that directly favor lenited forms over unlenited ones, since no such constraints were motivated by Experiment 1. The constraints that *are* made available by the experimental results are nevertheless able to account for a sizeable portion of the typology of lenition. I conclude that articulatory factors say less about lenition than traditionally thought, and that perceptual factors say more – and that theories of phonology that are committed to taking phonetics seriously must take notice.

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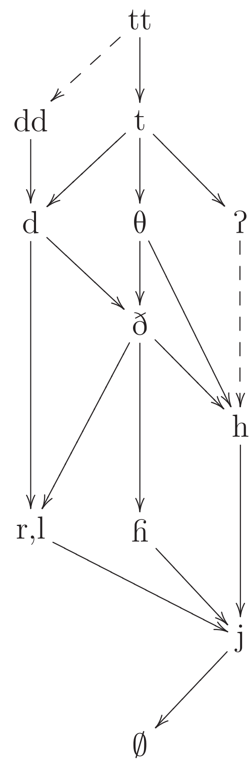
Chapter 1

Introduction

One of the goals of phonological theory is to account for typology – that is, to formulate testable hypotheses about why certain sound patterns are found in natural language while others seem to be systematically unattested. In some cases, the reason a given pattern does not exist is hypothesized to be purely cognitive – for example, that no phonological feature refers to a particular class of segments. In recent decades, however, the trend has been for explanations to be grounded in 'external' phonetic facts – for example, the perceptibility of the segments involved (Ohala 1981; Steriade 2001a), how their articulation interacts with the anatomy and aerodynamics of the vocal tract (Ohala 1983; Hayes 1999), or the types of diachronic changes that can lead to the pattern (Blevins 2004). The focus of this dissertation is on the types of phonetic grounding that have been proposed for a subset of the class of phonological patterns known as 'lenition'.

Figure 1.1: Schematic illustration of sound changes commonly termed 'lenition' in Bauer (2008), in turn derived from Hock (1986). Dashed lines show 'possible but unobserved changes' Bauer (2008, 606).



1.1 Lenition

'Lenition' refers to a loosely defined network of sound changes, especially when they occur intervocalically; figure 1.1 illustrates many of the changes to which this term is applied. Lenition is sometimes considered a distinct type of sound change, and is often presented as such in textbooks on historical linguistics (e.g., Crowley (1997, 37-41) and Campbell (2004, 44); both authors acknowledge that the term is not well defined). By extension, the term can also be applied to phonological alternations in which the surface realization of a phoneme is 'lenited'; this is the sense in which the term is used in this dissertation.

Lenition is generally understood as 'weakening' of the relevant segments; however, there is no more consensus on the meaning of the latter term than there is for the former. There have been a number of attempts in the literature to identify the defining property of lenition; Lavoie (2001, 12) classifies the various approaches into four categories:

1. "Lenition as deletion": lenition is any step along a chain of sound changes (such as those illustrated in figure 1.1) that end in [∅].

2. "Lenition as an increase in sonority": the changes that qualify as lenition involve an increase in sonority.

3. "Lenition as a decrease in effort": lenition is any sound change that involves substitution of an easy segment for a difficult one.

4. "Lenition as a decrease in duration and magnitude of gestures": lenition is any sound change that involves shorter or smaller gestures.

Note that these approaches define lenition in terms that are phonetic (gestural magnitude) or nearly so (sonority). An alternative would be to posit that the unity of lenition lies in the kind of abstract cognitive mechanisms that are the common currency of formal phonology; indeed, a classic Phonology 101 analysis of intervocalic lenition involves spreading of features such as [voice] or [continuant] from vowels to the targeted consonant.[1] However, arguments that the unity of lenition lies *solely* in the realm of formal phonology are rare (although see

[1] An analysis along these lines could account for the specific lenition processes that are the focus of this dissertation. Since my goal is to determine the extent to which *phonetic* factors contribute to our understanding of lenition, I do not pursue such an analysis here. See also Kirchner (2001b, 12-13) for arguments that the feature-spreading approach is not the most insightful analysis of lenition.

Harris (1990)). Instead, analyses of lenition that make use of formal tools such as Optimality-Theoretic constraints typically propose that those constraints have phonetic motivations (Kirchner 2001b; Kingston 2008).

A third approach is to deny that lenition is a single, unified phenomenon and instead view it as a tightly knit network of sound patterns with overlapping causes and properties. It is this last approach that I adopt as a working assumption. If research on the phonetic and phonological characteristics of lenition has shown us anything, it is that these sound changes have many properties in common, none of which matches perfectly to the canonical set of 'leniting' alternations. Any given property that is held up as 'what lenition really is' typically excludes some alternations traditionally called lenition (e.g., deletion is not an increase in sonority) while including others (e.g., final devoicing is not typically considered leniting but has been argued to involve effort reduction – although see §3.3.3). Indeed, the reasoning behind any attempt to determine *the* defining characteristic of lenition is essentially circular: Property X is associated with many of the alternations we call lenition. But we are not certain precisely which alternations really count as lenition. Fortunately, now that we know that lenition is defined by property X, we can use X to determine which alternations are leniting and which are not.

So as we continue to investigate individual causes of lenition – a research program to which this dissertation contributes – let us acknowledge the diversity of factors that are likely responsible for the network of sound patterns sketched in figure 1.1, and continue to retain 'lenition' as convenient cover term for this set of interrelated patterns, fuzzy boundaries and all. In this spirit, I will use the term 'lenition' to refer to the four specific sound patterns under investigation here (see (1) and (2) below). Note that this approach to lenition is consonant with another use of term: as a label for certain language-specific alternations with complex lexical and morphological conditioning. The patterns of this type for which the term is used are clearly fossilized and are no longer transparently 'lenition'-like; in addition to canonical alternations such as spirantization or gliding, they often include non-canonical alternations such as /m/ → [v] (Breton, Stump 1988, 459) or /n/ → [nj] (Nuu-chah-nulth, Kim and Pulleyblank 2009, 594).

1.2 Phonetic Bases of Lenition

This dissertation focuses on alternations that affect two features of intervocalic stops: voicing and continuancy. The four patterns that are of particular interest are schematized in (1) – (2).

(1) a. **Attested:** Intervocalic voiceless stops targeted for spirantization
(e.g., Tiberian Hebrew)
(i) /VpV/ → [VfV]
(ii) /VtV/ → [VθV]
(iii) /VkV/ → [VxV]

b. **Attested:** Intervocalic voiced stops targeted for spirantization
(e.g., Spanish)
(i) /VbV/ → [VβV]
(ii) /VdV/ → [VðV]
(iii) /VgV/ → [VɣV]

(2) a. **Attested:** Intervocalic voiceless stops targeted for voicing

(e.g., Warndarang)

(i) /VpV/ → [VbV]

(ii) /VtV/ → [VdV]

(iii) /VkV/ → [VgV]

b. **Unattested:** Intervocalic voiced stops never targeted for devoicing

(i) */VbV/ → [VpV]

(ii) */VdV/ → [VtV]

(iii) */VgV/ → [VkV]

Both voiced and voiceless stops can be targeted for spirantization intervocalically or in similar environments. In addition, voiceless stops can be targeted for voicing. Unattested, however, is another hypothetically possible change, in which intervocalica voiced stops are specifically targeted for devoicing (illustrated in (2b)). The fact that (1a), (1b), and (2a) are attested while (2b) is not is something that must be explained.

Note that it is not enough to say that the alternation of (2b) is unattested because "it wouldn't be lenition". First, this argument assumes that we know exactly what lenition is; as argued above, this is not the case. Second, unless the status of intervocalic devoicing as non-leniting is given some phonetic or other causal basis, the argument is essentially that intervocalic devoicing does not occur because it is very different from an attested process (voicing), and indeed is the reverse. There *do* exist phonological patterns that seem to be the reverse of each other (see, e.g., Crosswhite (2001) on two types of vowel reduction); thus, we are left with an argument that (2b) is unattested because it is different from patterns that *are* attested. The explanation does not explain.

If we seek to ground our account of the contrast between (1a) – (2a) and (2b) in the particular phonetic properties of the sounds involved, there are at least two places we might look – the articulatory characteristics of the relevant sequences, or their perceptual characteristics.[2] As discussed above, one traditional understanding of lenition has in fact been that it is a type of *articulatory* effort reduction. For cases of spirantization, the intuition is that since the gesture required to produce a fricative is of smaller magnitude than the gesture required to produce a stop, the fricative is less effortful than the stop; spirantization is therefore seen as a type of articulatory 'undershoot' along the lines of Lindblom (1983). Some evidence along these lines has been adduced by the EPG experiments of Lavoie (2001) and the model of the vocal tract detailed by Kirchner (2001b). For voicing of voiceless stops, the claim is essentially that having a period of voicelessness between two (voiced) vowels requires extra effort on the part of the glottis, while simply continuing modal voicing throughout the entire sequence is less effortful; Westbury and Keating (1986) and Kingston and Diehl (1994) present evidence for this view. This account suggests one explanation for the absence of intervocalic devoicing: as the reverse of intervocalic voicing, devoicing introduces a period of voicelessness between the vowels, increasing the difficulty of the sequence.

Despite its intuitive appeal, this claim is very difficult to test directly, forcing researchers to resort to the various indirect methods described above for investigating the relative difficulty of these segments in the appropriate environments. In addition, precisely because the articulatory account seems so plausible, there

[2]Naturally, these are not the only possibilities. Gurevich (2004) and Silverman (2006) discuss the interaction of lenition process with the pressure to avoid neutralization; see §2.3 for a discussion of these issues.

has been little investigation of other factors that might help us understand this type of lenition (although see Kingston (2008)). There may also be reasons to be a bit suspicious of the articulatory account: for example, from another perspective, we might expect fricatives to be *more* effortful than stops because they require precise placement of the active articulator (Bauer 2008, 609).[3] In addition, if lenited forms are articulatorily superior to unlenited forms, then we might expect lenition-like patterns to emerge in child language. Interestingly, though, Lleó and Rakow (2005) found in a study of Spanish-German bilingual children that instead of transferring the spirantization pattern to their German productions, children transferred *lack* of spirantization to their Spanish productions, beginning at about 2;6.[4] The evidence that lenited sounds are truly easier is far from clear.

Although discussions of phonetic grounding are dominated by articulatory considerations in the domain of lenition, there is evidence for other phonological patterns that perception – and, importantly, *mis*perception – plays an important role. For example, Ohala (1981) shows that listeners can compensate for coarticulatory effects among segments that are near each other, and proposes that overcompensation by listeners drives dissimilation-like processes. Hume (2003) argues that the likelihood of phonological metathesis is related to the ability of the listener to recover the intended order of the relevant sounds (and as related to the listener's native phonotactics). Blevins' (2004) typology of CHANGE, CHANCE, and CHOICE is intended to account for different ways in which the interaction between variable production and (mis)perception drives sound change.

[3] On the other hand, it has been argued by Lavoie (2001), among others, that spirantization results not in fricatives but rather in approximants, for which this difficulty would not arise.

[4] As the authors acknowledge, there are a number of independent factors that might have encouraged transfer in this direction – most prominently, that the bilingual children were being raised in Germany.

In this dissertation, I present the results of a series of experiments designed to test the possible perceptual and articulatory bases of lenition. The overarching goal is to determine whether – and if so, to what extent – phonetic realities match the typology of lenition and therefore suggest explanations for the range of attested patterns.

1.3 Outline of Dissertation

In chapter 2, I survey attested lenition processes that apply to intervocalic stops in order to establish the facts that we must account for.

Chapter 3 discusses a production experiment designed to elicit more and less effortful productions and investigates whether 'lenited' productions are truly less effortful, as claimed by articulation-based accounts of lenition. The data does not support the traditional view of lenition as straightforward effort reduction, but it does suggest that considerations of effort reduction may lead speakers to avoid 'extreme' articulations, a practice that may in turn provide precursors to lenition.

Chapter 4 reports the results of three perceptual experiments designed to test whether a perceptual account of the basic typology of (1) and (2) is viable. The results of Experiments 2 and 4 suggest that a perceptual account is consistent with the broad outlines of the typology, while Experiment 3 shows that the more fine-grained differences by place of articulation revealed in chapter 2 cannot be explained in the same way.

The combined results of Experiments 1 – 4 fail to support the traditional account of lenition by which lenited productions are articulatorily easier than unlenited ones: articulatory considerations appear to have less to say about lenition than usually thought, and perceptual considerations have more. Chapter 5 illustrates what a phonological analysis of lenition would have to look like in order to be consistent with the results of these four experiments. Chapter 6 concludes.

Chapter 2

Typology of Intervocalic Voicing and Spirantization

Since the goal of this dissertation is to arrive at a better understanding of the phonetic bases of the lenition of intervocalic stops, its starting point must naturally be a typology of such lenition. The following survey is based on the work of Gurevich (2004), who has codified previous typological databases of lenition by Lavoie (2001) and Kirchner (2001b) and expanded them by compiling the segment inventories of the relevant languages. Gurevich's database includes 153 languages, of which 136 (those for which she was able to obtain a full consonant inventory) are analyzed here. The table in appendix 7.1 summarizes her findings as they are relevant to this study.

As acknowledged by its creators, this database is not exhaustive, nor is it designed to be a typologically balanced sample. The numbers reported below therefore have dubious statistical value. The importance of this survey is that it presents a rough picture of the types of lenition processes affecting intervocalic stops that are attested in natural language, and it provides suggestive evidence as to whether some kinds of processes are more common than others. But the smaller the numbers involved (especially when very specific processes are under consideration), the more skeptical we should be of how representative they are.

Gurevich's (2004) database contains information on a broad range of lenition processes; thus, only a subset of the processes described in it affect intervocalic stops (93 of the languages have at least one such alternation). §2.1 gives an overview of the basic types of processes found in the database that affect intervocalic stops. §2.2 examines the effect of place of articulation of the targeted stops, and §2.3 examines the role of contrast maintenance.

Two kinds of counts are given in the following tables: counts of alternations and counts of languages. Here, an 'alternation' is a change affecting a single segment and may in fact represent only part of a larger phonological phenomenon. In Tiberian Hebrew, for example, voiced and voiceless stops (a total of six segments) undergo spirantization; this pattern is coded as six separate 'alternations' (one for each segment). This method of coding is intended to reflect the extent of the effect of lenition and to aid the breakdown by place of articulation detailed in §2.2; the term 'alternations' is adopted for convenience and is not intended to represent a claim about the phonological (dis)unity of the relevant phenomena.

2.1 Lenition of Intervocalic Stops: General Observations

Table 2.1 summarizes the lenition processes in the database that target voiceless stops, and table 2.2 those that target voiced stops. 61 languages in the database lenite voiceless stops, and 56 lenite voiced stops. Voicing is overwhelmingly the most common process affecting voiceless stops, followed by spirantization and simultaneous voicing and spirantization. Spirantization is most common for voiced stops. A significant number of stops of both types undergo flapping (only alveolars and retroflexes are affected), and several more undergo approximantization.

Table 2.1: Lenition of voiceless stops

Type of Lenition	**Number of Languages**	**Number of Alternations**
Voicing	26	90
Spirantization	17	29
Both	11	22
Other	14	29
Approximantization	*5*	*16*
Flapping	*5*	*5*
Debuccalization	*3*	*5*
Glottalization	*3*	*3*

2.2 Place of Articulation

It is not a given that all voiceless stops, or all voiced stops, will behave the same way with respect to lenition. One factor that might be expected to have an

Table 2.2: Lenition of voiced stops

Type of Lenition	**Number of Languages**	**Number of Alternations**
Spirantization	42	81
Other	26	35
Flapping	*18*	*18*
Degemination	*2*	*8*
Approximantization	*3*	*3*
Lateralization	*2*	*2*
'Lenition'	*2*	*2*
Debuccalization	*1*	*1*
Deaspiration	*1*	*1*

effect on a given stop's behavior is its place of articulation; indeed, to the extent that the effect of place on stops' perceptual or articulatory properties is mirrored in the typology of lenition, we have correspondingly strong (or weak) evidence that those phonetic factors are driving the attested phonological patterns. This section compares how often intervocalic stops lenite at three major places of articulation; if stops at one place are especially prone (or resistant) to a certain kind of lenition, we may expect to find some phonetic motivation for that fact.

Stops are grouped into three broad categories of place: labials, coronals (dentals, alveolars, and retroflexes), and dorsals (velars). Labialized and palatalized consonants are classified with their primary place of articulation; for example, labialized velars are classified as dorsals. Palatals and uvulars are excluded entirely.

For each place of articulation, table 2.3 gives the number of languages with a voiceless stop at that place and, of those, the number that target that stop for voicing intervocalically (possibly among other environments). The first column in table 2.4 counts languages that single out one place of articulation for voicing; the second column counts languages that voice at every place but one. (Only languages with voiceless stops at all three major places were counted for the latter table.)

Table 2.3: Number of languages with voicing of voiceless stops by place

POA	Number with Voiceless Stop	Number with Voicing	Percent with Voicing
Labial	122	21	17%
Coronal	133	24	18%
Dorsal	134	23	17%

Table 2.4: Number of languages with selective voicing of voiceless stops by place

POA	Only Target	Only Non-target
Labial	1	1
Coronal	1	0
Dorsal	1	0

The rate of voicing of voiceless stops is essentially identical at all three major places of articulation: 17% of the languages voice intervocalic labials; 18%, coronals; and 17%, dorsals. Among languages with voiceless stops at all three places of articulation, no place seems to be consistently singled out to be voiced (or not voiced); however, as there are only four languages in the database with patterns of this type, it is impossible to draw firm conclusions. Overall, place of articulation does not seem to affect the likelihood that a given voiceless stop will be targeted for intervocalic voicing.

Tables 2.5 and 2.6 are analogous to tables 2.3 and 2.4, respectively; they summarize the interaction between place of articulation and intervocalic spirantization of voiceless stops. Again, the rate of spirantization is essentially the same at each place (8% for labials, 5% for coronals, and 7% for dorsals). Similarly, no place stands out as frequently singled out for (non-)spirantization, except perhaps that coronals are less likely to be the lone spirantizers than labials or dorsals. Overall, though, spirantization, like voicing, does not seem to interact with place of articulation.

Table 2.5: Number of languages with spirantization of voiceless stops by place

POA	Number with Voiceless Stop	Number with Spirantization	Percent with Spirantization
Labial	122	10	8%
Coronal	133	6	5%
Dorsal	134	9	7%

Table 2.6: Number of languages with selective spirantization of voiceless stops by place

POA	Only Target	Only Non-target
Labial	5	1
Coronal	1	1
Dorsal	5	2

Tables 2.7 and 2.8 give the same information for the spirantization of voiced stops. Here, a slightly different picture emerges: coronals are less likely than either labials or dorsals to spirantize. They spirantize at a lower rate (19% versus 34% for labials and 30% for dorsals), and this difference even approaches significance ($p = .025$ for the difference between labials and coronals and .10 for the difference

between dorsals and coronals, without adjustment for multiple comparisons). In addition, of languages with voiced stops at all three major places, seven spirantize labials and dorsals to the exclusion of coronals; labials are never singled out in this way and only one language (Dahalo) singles out dorsals as non-spirantizing. However, it is possible that the apparent recalcitrance of coronals simply reflects the fact that only coronals (alveolars and retroflexes) are subject to flapping – in other words, many coronals that would otherwise be targeted for spirantization flap instead. Indeed, if we add the coronals that flap to the counts in table 2.7, the number of coronals targeted for lenition rises to 32 (34%), the same rate as labials and dorsals.

The rate of spirantization for labials is very close to that of dorsals. The counts suggest that if there is a difference at all, spirantization may preferentially target labials over dorsals. Labials spirantize at a slightly higher rate (although the difference is not significant; $p = .67$), are singled out for spirantization in nine languages versus five for dorsals, and are never the only place *not* spirantized. But since the numbers involved are extremely small and the language sample is not necessarily balanced, it is possible that this trend is an artifact of this particular dataset.

Table 2.7: Number of languages with spirantization of voiced stops by place

POA	**Number with Voiced Stop**	**Number with Spirantization**	**Percent with Spirantization**
Labial	96	33	34%
Coronal	95	18	19%
Dorsal	89	27	30%

Note that these findings do not necessarily agree with statements elsewhere in

Table 2.8: Number of languages with selective spirantization of voiced stops by place

POA	Only Target	Only Non-target
Labial	9	0
Coronal	3	7
Dorsal	5	1

the literature on the propensity of various segments to lenite. For example, Harris (1990, fn. 3) cites Foley (1977) as claiming that velars lenite more than labials, which in turn lenite more than coronals. To the extent that Gurevich's database supports any differences by place of articulation, it suggests that if anything, velars are *less* likely to spirantize than labials.

2.3 Segment Inventory and Contrast Maintenance

It is well known that phonological patterns are sensitive to the need to maintain contrasts within the segment inventory (see Flemming (2002) and Padgett (2003), among many others). Gurevich (2004) shows that lenition processes as a class seem to be particularly sensitive to (the avoidance of) neutralization: only a handful of the lenition processes in her database lead to neutralization. Since these types of systemic pressures are known to influence lenition processes such as intervocalic spirantization, it is possible that factoring out the effects of contrast maintenance would lead to a different picture of the propensity of various places of articulation to spirantize.

For example, the data in the previous section provided suggestive evidence that voiced coronals are less prone to spirantize than voiced stops at other places of articulation, and that voiced labials may be slightly more prone to spirantize than voiced dorsals. If, for independent reasons, systemic pressures have a disproportionate influence on certain places of articulation, then we could conclude that the observed asymmetries are not the result of an inherent tendency for languages to spirantize some places of articulation more than others.

There are at least two ways systemic facts might interact with spirantization. First, if a language already has a contrast between a voiced stop and a voiced spirant at some place of articulation, then spirantization at that place of articulation would lead to neutralization and is therefore likely to be avoided. Therefore, if there are more languages with [ɣ] than with [β], then there are more languages that are free to spirantize labials than dorsals without fear of neutralization.

Second, if a language has voicing of voiceless stops in at least some of the contexts where it already has voiced stops, then spirantization would be a way to maintain the contrast between the two series in the relevant environments. (In fact, Silverman (2006) argues that pressure from intervocalic voicing is the primary, or perhaps the only, motivation for intervocalic spirantization.) Therefore, if there are more languages that voice /p/ in the relevant contexts than languages that voice /k/, then there are more languages that are pressured to spirantize labials than dorsals in order to maintain the relevant contrast.

Tables 2.9 – 2.11 present counts of the languages in Gurevich's (2004) database, broken down by the systemic possibilities discussed above. Each table includes only those languages that have a voiced stop at the relevant place of articulation (thus, those languages with a possibility of spirantizing). The first two lines of each table report the number of languages with and without the relevant contrasting voiced fricative; the tables for labials and coronals also report the number of languages with [v] and [z], respectively – although spirantization yields these segments less often than [β] and [ð], it is possible that they might nevertheless be systemically relevant. The second two lines of each table report the number of languages with and without voicing of voiceless stops at the relevant place of articulation, where voicing takes place in at least some of the same environments as spirantization. Languages that were reported to lack the relevant voiceless stop altogether were included and were classified as not having voicing, since any spirantization that does occur takes place without being 'pushed' by voicing of another series.

Table 2.9: Number of languages with spirantization of /b/ by presence of /β/ and voicing of /p/

	Spirantization	**No Spirantization**	**Percent with Spirantization**
/β/ (/v/) Present	0 (9)	4 (15)	0% (38%)
/β/ Absent	24	44	35%
/p/ → [b]	2	3	40%
/p/ ↛ [b]	31	60	34%

Table 2.10: Number of languages with spirantization of /d/ by presence of /ð/ and voicing of /t/

	Spirantization	**No Spirantization**	**Percent with Spirantization**
/ð/ (/z/) Present	0 (12)	4 (36)	0% (25%)
/ð/ Absent	6	37	14%
/t/ → [d]	3	2	60%
/t/ ↛ [d]	16	75	18%

At all three places of articulation, languages are less likely to spirantize at

Table 2.11: Number of languages with spirantization of /g/ by presence of /ɣ/ and voicing of /k/

	Spirantization	No Spirantization	Percent with Spirantization
/ɣ/ Present	1	8	11%
/ɣ/ Absent	26	54	33%
/k/ $\rightarrow$ **[g]**	2	2	50%
/k/ $\not\rightarrow$ **[g]**	25	60	29%

a given place of articulation when the spirant is already present contrastively. No languages with /β/ or /ð/ spirantize /b/ or /d/, respectively, and only one language with /ɣ/ spirantizes /g/ (Shina). By contrast, languages without contrasting spirants spirantize at a rate of 35%, 14%, and 33% for labials, coronals, and dorsals, respectively. However, since none of these differences are statistically significant, they should be interpreted with caution. In addition, the presence of /v/ or /z/ seems to have no effect on the propensity of a language to spirantize /b/ or /d/; the rates of spirantization for languages with and without these segments are very similar.

These results suggest that Gurevich's conclusion about lenition processes as a whole holds for intervocalic spirantization specifically as well: spirantization is sensitive to contrast maintenance and avoids neutralization. In addition, we see that a few more languages have /ɣ/ than /β/; it is just possible, then, that it is a higher incidence of /ɣ/ than /β/ that leads to the smaller number of languages spirantizing dorsals than labials. In order to draw firmer conclusions, though, a more rigorous typological study would be necessary. Only four languages have /ð/; thus, it is highly unlikely that the low rate of spirantization of /d/ is the result of languages avoiding neutralization with /ð/.

The numbers above also suggest a role played by voicing of voiceless stops. At each place of articulation, a greater proportion of languages with voicing also spirantize than languages without voicing. Again, though, the numbers are too small to be statistically significant. (The results for the coronals come closest; $p = .082$.) In addition, the number of languages with voicing is very similar at each place of articulation, suggesting that independent patterns of voicing of voiceless stops are not likely to account for the different rates of spirantization at various places of articulation.

Finally, these results present us with the opportunity to investigate the strong and interesting claim of Silverman (2006) referred to above. Silverman discusses the case of Corsican, which has both intervocalic voicing of voiceless stops and intervocalic spirantization of voiced stops. He argues that intervocalic spirantization is not a 'natural' sound change, but rather one that is motivated by considerations of contrast maintenance:

> The idea, then, is that intervocalic spirantization arises *in functional response* to the phonetically natural #[t]-V[d]V alternation. Just as [t] naturally moves towards [d] intervocalically largely for *phonetic* reasons, the *other* [d] here will *not* be pushed in any particular direction for phonetic reasons, but instead will gradually be pushed toward [ð] largely for *functional* reasons, since tokens with fricative variants were communicated more successfully to listeners, while variants that remain [d]-like will be more confusable with those intervocalic [d]s that alternate with word-initial [t]....
>
> To summarize, the example of Corsican reveals something very important about the inter-relatedness of contrastive sounds that each has its own [sic] set of allophonic alternants: while phonetic pressures may pull one sound towards a context-specific *more* natural state, functional pressures may, in response, push an opposing sound to a

> context-specific *less* natural state.
> (pp. 165-166, italics original)

Although Silverman is likely correct that intervocalic voicing encourages intervocalic spirantization – and the data above provides additional evidence for this view – his claim that neutralization avoidance is the *only* (or even the primary) motivation for intervocalic spirantization cannot be supported. Of the languages with spirantization counted in tables 2.9 – 2.11, the vast majority do *not* also have voicing of voiceless stops (94%, 84%, and 93% for labials, coronals, and dorsals, respectively);[1] thus, Silverman's claim that "[spirantization] is usually found in languages that *also* have a #[t]-V[d]V alternation as well" (p. 165) is simply false. If spirantization is unnatural but can be forced by voicing of another stop series, where do all of the languages with spirantization but no voicing come from? The results of Experiment 2 suggest that part of the answer may be voiced stops' high degree of confusability with voiced spirants, although the question of what induces voiced stops to change at all remains unanswered. Again, articulatory factors may play a role, although as Silverman (2006, 165) correctly points out, any claims about the influence of articulation must be supported with more direct evidence than is currently available. Indeed, the results of Experiment 1 support Silverman's contention that considerations of effort reduction do not directly encourage intervocalic spirantization.

Incidentally, Silverman's argument from typological evidence that intervocalic spirantization is articulatorily unnatural is not supported by Gurevich's data either. He argues that intervocalic spirantization is shown to be unnatural because

[1] Northern Corsican, which is Silverman's case study, was excluded from this analysis because its segment inventory is not given in Gurevich (2004). Even if it is included, the numbers remain high: 91%, 80%, and 89% for labials, coronals, and dorsals, respectively.

intervocalic *voiceless* stops rarely spirantize, especially not to voiced spirants. However, table 2.1 above shows that although spirantization of voiceless stops is less common than either voicing of voiceless stops or spirantization of voiced stops, the /T/ → [S] pattern is nevertheless robustly attested, and even the /T/ → [Z] pattern is far from nonexistant. Thus, intervocalic spirantization is a well-attested option across languages, places of articulation, and voicing of the affected stops.

Chapter 3

Articulatory Effort Reduction

This chapter reports the results of an experiment designed to explore whether articulatory effort reduction plays a role in the lenition of intervocalic stops. Previous studies of articulatory effort, I argue below, are lacking in that they use indirect means to assess effort: either abstract models of the articulatory apparatus, or post-hoc reasoning from the characteristics of the relevant gestures to the relative effort involved. Experiment 1 takes an approach that is, to my knowledge, nearly unique in the literature: it attempts to observe effort reduction in action in the laboratory, by creating conditions meant to encourage subjects to use less effort in speaking.

The premise of the experiment is that a subject who is tired or impaired will produce less effortful articulations than he otherwise would; therefore, by comparing the speech of subjects in normal and tired conditions, we can identify as ‘easy’ those productions that are favored in the tired condition. Of course, saying that we would like to study tired speech is one thing, and actually inducing tiredness in a laboratory setting is another. In Experiment 1, I simulated tiredness with intoxication, comparing the speech of subjects who were intoxicated with the speech of the same subjects when they were sober. I do not claim that inducing intoxication is the only or even the best way to simulate tiredness in the laboratory; indeed, it is possible that each of the conceivable methods of inducing tiredness or other general impairment (intoxication, exercise, sleep deprivation, emotional stress, etc.) has its own unique characteristics and gives us only a partial picture of speech under impairment. Experiment 1 is intended as an initial exploration of what impairment of some kind might tell us about articulatory effort.

3.1 Assessing Articulatory Effort

Most previous assessments of articulatory effort in the literature fall into one of two categories. In the first type, a researcher argues that some characteristic of a certain type of production causes that production to require more effort than productions that lack that characteristic. The following representative quotations illustrate some of the characteristics of speech sounds that have been claimed to affect their difficulty:

Displacement of articulator "Extreme displacements and extreme velocities are avoided....we find that speech production appears to operate as if physiological processes were governed by a *power constraint* limiting energy expenditure per unit time." (Lindblom 1983, 231)

Speed of articulator movement "Matthies et al. (2001) report that the peak velocities of lip movements are greater for clear speech than for conversational speech for /iCu/ syllables. These studies demonstrate that the production of clear speech requires more effort and expends more energy than does the production of conversational speech.” (Uchanski 2005, 226)

Precision of gesture “Fricative closures require more control and thus more effort.” (Lavoie 2001, 165)

Stability “...the coupled-oscillator view on slips of the tongue sees errors as arising from a move towards optimization; they are intances of optimal stability. In this sense, if we start producing a /t/ and a /k/ at the same time instead of alternating between them, we are reducing articulatory effort.” (Pouplier 2003, 2246)

Tenseness of gesture “It seems reasonable to posit that [r] is more difficult articulatorily than [ɾ]. This is based on...the inherent tenseness of the trill articulation” (Padgett 2009, 440)

Energy expended “...assimilation, defined as reduced distance between two sequentially timed articulatory targets, implies less work per unit time. In a mechanical system such a restructuring of a frequently used sequence of targets will obviously, in the long run, lower energy costs....it does not seem unreasonable to hypothesize by way of analogy that [languages undergo assimilation] to optimize motor control by minimizing physiological energy expenditure.” (Lindblom 1983, 237-238)

Arguments of this type are a good first step in our attempt to understand articulatory effort, but they are far from conclusive. First, it is not always clear whether the observed differences among gestures are really large enough to make a difference. For example, Kingston (2008, 1) argues that lenited segments do not require less effort than unlenited segments, because the differences between the two productions in distance traveled by the articulators and in time are extremely small. Second, the metrics of effort listed above may conflict. For example, fricatives require a smaller gesture than stops (suggesting that they require less effort), but they also require more precision (suggesting that they require more). There is not always an obvious way to combine these metrics and determine the overall amount of 'effort' required for a given production.

The second way researchers have assessed articulatory effort involves building an abstract model of the speech apparatus and comparing the production requirements predicted by the model for different segment types. Such approaches generally interpret one parameter (or more) of the model as a measure of articulatory effort, with a given production's value for that parameter translating into the degree of effort it requires. Notable examples of models of this type include the following:

- Lindblom and Sundberg (1971), Lindblom (1983), and Lindblom (1990) describe a model of tongue shapes and the possible shapes associated with various consonants and vowels. Lindblom (1983) argues that coarticulation between consonants and vowels is predicted by a constraint that penalizes extreme parameter values in the model.

- Westbury and Keating (1986) describe a model of airflow in the vocal tract. They define 'easy' articulations to be those that require the slowest articulator movements, and show that the model predicts voicing to be easier in some contexts (intervocalically) than in others (initially or finally). The same model has been applied by Hayes (2004[1999]) to other environments.

- Kirchner (2001b) constructs a mass-spring model of the vocal tract (along the lines sketched in Lindblom (1983, 227-229)). He defines effort as the total force exerted throughout a production, showing that the model predicts that certain types of lenited consonants are less effortful than their unlenited counterparts (for example, that singleton stops are less effortful than geminates).

- Nam et al. (2009) model articulatory gestures as coupled oscillators. They assume that in-phase (0°) coupling is the most stable mode and anti-phase (180°) coupling the second most stable, as established in research on coordinated movement of human limbs; they also follow earlier work in associating the two modes with CV and VC sequences, respectively. They show that a model based on these two assumptions makes a number of correct predictions, including earlier acquisition of CV relative to VC by children.

Models of this type are an improvement over case-by-case reasoning in that they attempt to model larger systems, and often offer at least an in-principle solution to the problem of conflicting measures of effort. For example, Kirchner (2001b) incorporates into his metric of force expended the dimensions of speed of articulator movement (greater speed requires more force), distance traveled (a greater distance requires more force), and precision (precise gestures require several counteracting forces to keep the relevant articulator at exactly the right position). All these factors are collapsed onto a single dimension so that the net effort expended can be determined.

However, abstract models like these still require the researcher to choose some parameter of the model as the one that best represents 'effort'; although the methods described above involve reasonable choices, there is no guarantee that they are the *best* choices in terms of describing which sounds are more effortful than others. In addition, since models are by definition simplifications of real-world phenomena, there is always the danger of putting into these models what we expect to get out of them. It is not surprising, for example, that if we describe the articulatory apparatus as a means of applying forces to various masses, then it takes more force to cause a given mass to move farther or faster; or that if we assume that children are biased towards more stable CV sequences over less stable VC sequences, then they acquire CV sequences first.

In Experiment 1, I take a different approach altogether. Rather than trying to reason through whether lenited productions are more or less effortful than unlenited productions, I attempt to create conditions in the laboratory that will encourage subjects to use less articulatory effort than they otherwise would. If subjects favor one type of production in the 'low-effort' condition more than they do in the control condition, then we have evidence that that production requires less effort than productions that are *not* favored in the 'low-effort' condition. I am aware of only one other study along these lines in the literature: Walter (2008) reports experimental results showing that qualitative lenition is more likely in consonants with an identical consonant in an adjacent syllable.

In this study, I encourage effort reduction in subjects with intoxication. If this method is successful, it will tell us *which* segments are easier than others, but not *why* they are easier. As detailed in §3.2, intoxication impairs subject performance in a number of different ways, any of which might or might not be responsible for any effort reduction revealed by Experiment 1. Determining what factors contribute to articulatory effort and how they interact is an important topic for future research. However, the necessary first step is to acquire more solid evidence as to which productions require more or less effort in the first place, and that is the goal of Experiment 1.

3.2 Physical and Linguistic Effects of Alcohol Consumption

Alcohol is a depressant and is known to impair cognitive and motor function (Chin and Pisoni 1997). At small doses, alcohol may actually increase performance slightly on some tasks (Chin and Pisoni 1997, 19-20,22); however, this effect seems to be limited to blood alcohol concentrations well below the level of .10 achieved in this study (Hollien and Martin 1996, 109-111). In general, intoxication impairs both speed and accuracy on tasks, and at levels above .10 impairs fine motor performance (Chin and Pisoni 1997, 21-22).

By far the most common documented effect of intoxication on speech is an overall lengthening effect; see, e.g., Lester and Skousen (1974, 233-234), Pisoni et al. (1986, 138), Johnson et al. (1990), Künzel (1992, 33,36), and Hollien and Martin (1996, 125). Intoxication has also been reported to result in expanded (Künzel 1992; Watanabe et al. 1994, 341) and more variable (Pisoni et al. 1986, 141) pitch ranges. Alcohol induces production errors at the segmental level (Künzel 1992; Hollien and Martin 1996, 125); specific errors that have been documented include lengthening of vowels and consonants, deletion, changes in nasality, and distortions of [s] (Lester and Skousen 1974; Künzel 1992; Pisoni et al. 1986). Künzel (1992, 33) observes substitution of [ð] for [d] and attributes the change to incomplete articulation. Purnell (2010) observes what appears to be a rotation of the vowel space (at least for front vowels) in intoxicated subjects.

There is some evidence that intoxication encourages devoicing, especially word-finally (Lester and Skousen 1974, 234). Pisoni et al. (1986) observe more lengthening in intoxicated speech in voiceless segments than in voiced segments. By contrast, Swartz (1992) observes no overall change in voice onset time in intoxicated speech. Watanabe et al. (1994, 346) document swelling of the vocal folds following consumption of alcohol, which may contribute to changes in subjects' propensity to produce voicing.

In addition to its topical effects on the vocal folds, there are a number of other mechanisms by which alcohol may affect speech. Alcohol interferes with proprioception (Wang et al. 1993; Tiplady et al. 2005), such that subjects become less accurate in their ability to move their arms a prespecified distance or draw figures of a prespecified size (when unable to see their arms or hands). Tiplady et al. also observe an increase in handwriting size under intoxication. The strongest effect is found for writing of unfamiliar orthographic characters, and the weakest effect for signatures, suggesting that alcohol has the least influence on highly practiced motor routines. Hellekant (1965) observes paralysis of certain fibers in the tongues of cats when exposed to alcohol; however, it is worth noting that Hellekant finds this effect only for alcohol concentrations above about 4.1 M, while the alcoholic drinks administered in this experiment (equal parts orange juice and 80-proof vodka) had a slightly lower concentration, approximately 3.4 M. Finally, in connection with the effects of intoxication on voicing in their study, Pisoni et al. (1986, 144) suggest that alcohol impairs subjects' ability to coordinate different gestures, particularly oral gestures and control of the vocal folds.

Thus, alcohol affects subject performance in a number of ways, and it also affects speech. Several of the specific effects of alcohol parallel the metrics of articulatory effort discussed above:

- Reduced speed of subject performance may decrease the speed at which subjects can move their articulators
- Impaired accuracy may decrease subjects' ability to effect precise placement of their articulators
- Alcohol as a depressant may limit the overall amount of energy subjects are able or willing to expend
- By impairing subjects' overall cognitive abilities, alcohol may impair subjects' ability to manage complex patterns of gestural coordination and cause them to revert to more 'stable' patterns

The fact that alcohol impairs cognitive and motor function in these ways, and the fact that intoxicated subjects *do* make more speech errors, suggest that alcohol consumption is a promising way to encourage subjects to expend less articulatory effort. Indeed, some of the speech errors documented under intoxication (such as substitution of [ð] for [d]) look tantalizingly like the types of lenition processes being investigated here.

However, intoxication is most relevant to the study of articulatory effort in general to the extent that it induces or exaggerates behavior that has other causes as well. In other words, if intoxication has some effect on speech production that causes subjects to lenite, but *only* intoxication affects speech in that way, then lenition by intoxicated subjects probably does not tell us much about what drives lenition in general. It is unlikely that lenition never occurs in teetotalling communities! For some of the effects of alcohol (such as a general impairment of fine motor control), it seems quite likely that there are other ways to produce similar effects; for others, however (such as swelling of the vocal folds), it is less clear that we are not dealing with something alcohol-specific.

It is entirely possible, therefore, that in the final analysis intoxicated speech tells us little that is relevant to the role of articulatory effort in phonological patterns. But in the absence of more direct evidence concerning which productions are more difficult than others, I submit that this method is worth serious consideration. In addition, because the physical effects of alcohol are so varied, and because the articulatory apparatus is so complex, I am not comfortable pointing to any one effect of alcohol and claiming that that effect is the sole or primary cause of the results seen in Experiment 1. Indeed, it would be irresponsible to rule out intoxication entirely as a tool for investigating effort reduction simply because it might have other effects as well. No method of studying articulatory effort is perfect. We simply do not know the extent to which the results of this method are or are not specific to intoxicated speech – and we cannot know until we have tried it. I view this experimental method as an important early step in a research program that attempts to observe effort reduction in action.

3.3 Experiment 1

3.3.1 Design

Stimuli

Three sets of stimuli were used in the experiment; all were real words of English. A full list of stimuli is included in appendix 7.2. The ‘effective contrast’ (frequency-weighted neighborhood density, Ussishkin and Wedel (2009)) of each stimulus was calculated from the frequency data in the CELEX database (Baayen et al. 1995); within each set, stimuli were chosen from as narrow a range of EC values as possible to ensure comparability among different subsets of stimuli.

The ‘nasal-stop’ set consisted of 56 disyllabic words with an intervocalic nasal-stop cluster (e.g., *amber*); each possible stop ([b], [p], [d], [t], [g], or [k]) was represented by 10 stimuli, except for [g], for which there were 6 stimuli. All words had primary stress on the first syllable and no stress on the second syllable.

The ‘lenition’ set consisted of 72 disyllabic words with a single intervocalic stop (e.g., *buggy*); each possible stop was represented by 12 stimuli. All words had primary stress on the first syllable and no stress on the second syllable.

The ‘CVC’ set consisted of 136 words with the shape CVC; each of the vowels and diphthongs of English ([i], [ɪ], [ɛ], [æ], [a], [ʌ], [ʊ], [u], [eɪ], [oʊ], [aɪ], [aʊ], or [ɔɪ]) was represented by 12 stimuli, except for [ʊ], [aʊ], and [ɔɪ], for which there were fewer stimuli. All of the consonants in these stimuli were obstruents. These stimuli are treated as fillers in the analyses below and are not analyzed further.

Participants

Eight subjects participated in Experiment 1; all were undergraduate or graduate students at UC Santa Cruz and were naïve to the purposes of the experiment. One of these subjects, subject 00, was a graduate student in linguistics; her results do not differ noticeably from those of the other subjects and are therefore included. To be eligible to participate in the experiment, each subject was required to

- be 21 years old or older,
- regularly consume at least one alcoholic drink per week,
- have consumed enough alcohol in a single sitting within the previous year to have likely raised his or her blood alcohol content (BAC) to .10 or higher,
- not be at risk for alcoholism according to the Michigan Alcoholism Screening Test,
- not be taking any medications that proscribe the consumption of alcohol,
- not be pregnant,
- be a native speaker of English, and
- never have been diagnosed with any speech impediment or hearing deficit.

Table 3.1 gives each participant's sex, whether that participant completed the sober or intoxicated condition first, and the participant's BAC at the beginning and end of the recording session in the intoxicated condition.

Table 3.1: Participants in Experiment 1. BAC_i and BAC_f are the participant's BAC at the beginning and end, respectively, of the recording session in the intoxicated condition

Subject	**Sex**	**First Session**	**BAC$_i$**	**BAC$_f$**
00	F	sober	.10	.07
01	F	intoxicated	.09	.07
02	F	intoxicated	.11	.09
03	M	sober	.12	.10
04	M	sober	.10	.13
05	M	intoxicated	.10	.09
06	F	sober	.10	.07
07	M	sober	.10	.18

Procedure

Each subject was recorded in both the sober condition and the intoxicated condition. With the exception of subject 00, the two recording sessions took place on separate days; the order of the two sessions was varied across subjects. Sessions followed the following procedure:

1. For the intoxicated condition, the subject was asked not to consume alcohol for 12 hours before the session began, and not to eat for 2 hours before the session.

2. At the beginning of each session, the subject read out loud a printed list of the stimuli to ensure that the subject was familiar with all of the words and had seen them all recently.

3. In the intoxicated condition, alcohol was administered so that the subject had a BAC between .10 and .12. (This level is slightly above .08, the legal limit for driving in the United States.)

(a) The initial dose of alcohol (equal parts 80-proof vodka and orange juice) was half of what was calculated to be necessary to bring the subject's BAC to between .10 and .12, based on the subject's sex and weight.

(b) After the subject finished the initial dose, he or she was given a Breathalyzer test and, if necessary, received further smaller doses of alcohol until the window of .10 – .12 was reached.

4. The subject made the recording alone in a sound-attenuated booth. Stimuli were presented one by one in random order on a computer screen; the subject read each word in the frame sentence "I SAID ___ already" and pressed the space bar to move on to the next word. Each stimulus was presented twice; the entire recording session took 20 – 30 minutes.

5. In the intoxicated condition, the subject remained in the lab until his or her BAC had declined to .04 or below.

3.3.2 Measurements

Subjects' recordings were analyzed in Praat (Boersma and Weenink 2007). The following sections describe the landmarks that were identified for each type of stimulus and how they were placed.

All Stimuli

The following landmarks were identified in all tokens, regardless of stimulus type.

Beginning of utterance (U_i) The beginning of the utterance (that is, the frame sentence) was defined as the beginning of the (regular or irregular) glottal pulses of the *I*.

End of utterance (U_f) The end of the utterance was defined as the first point in the [i] of *already* that was followed by a period of silence (that is, a period with no energy at any point in the spectrum). Subjects commonly produced breathy voice at the end of the frame sentence, sometimes making such a point difficult to identify.

Beginning of stimulus (W_i) The way in which the beginning of the stimulus was defined depended on the initial segment of the stimulus.

For stimuli beginning with a vowel or sonorant consonant, W_i was placed after the release of the [d] of *said* and any associated aspiration or other turbulent noise. If the subject paused between *said* and the stimulus, W_i was placed at the first glottal pulse of the stimulus.

For stimuli beginning with a stop or affricate, W_i was placed at the closure of the [d] of *said*. This location was chosen because in the vast majority of cases, subjects did not produce a separate release for the [d] of *said*, and it was therefore impossible to distinguish between the closure of the [d] and the closure of the initial consonant of the stimulus. In the few tokens that did have a separate release after *said*, W_i was nevertheless placed at the closure of the [d] for the sake of consistency.

For stimuli beginning with a fricative, W_i was placed at the beginning of the turbulent noise associated with the frication.

End of stimulus (W_f) The way in which the end of the stimulus was defined depended on the final segment of the stimulus.

For stimuli ending with a stop, W_f was placed after the release of the stop and any release or aspiration associated with it.

For stimuli ending with a fricative or affricate, W_f was placed at the end of the turbulent noise associated with the frication.

For stimuli ending with a nasal, W_f was placed at the point where the antiformants and decreased intensity associated with the nasal ended.

For stimuli ending with a vowel or sonorant consonant, W_f was placed at the beginning of the formant transitions between the final segment of the stimulus and the [a] of *already*. In most cases, this final segment was either [i], in which case the beginning of the F2 transition was used, or [ɹ], in which case the beginning of the F3 transition was used.

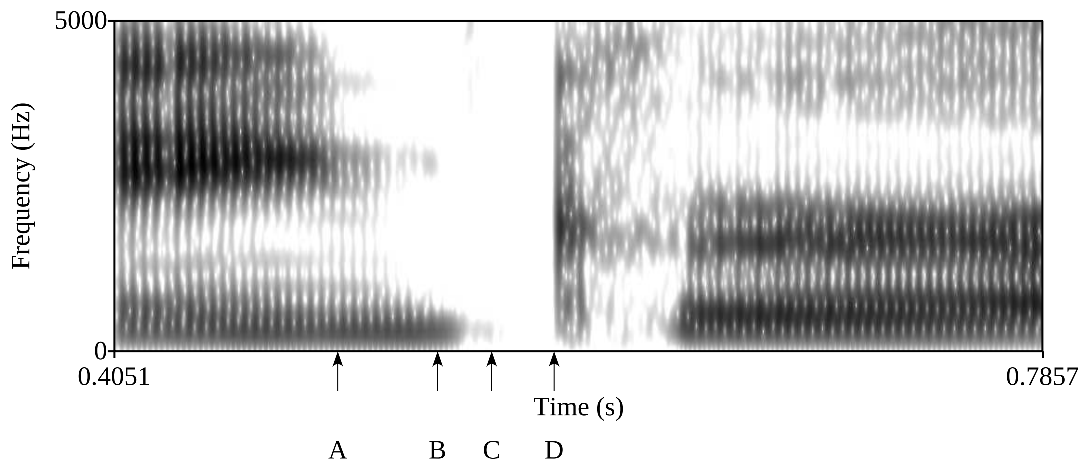
Closure of [d] of *said* (S_{clo}) For all stimuli that did *not* begin with a stop or affricate (that is, those for which W_i was not placed at the closure of the [d] of *said*), an additional landmark S_{clo} was placed at the closure.

End of voicing of [d] of *said* (S_{voi}) The end of voicing of the [d] of *said* was defined as the last glottal pulse following S_{clo}. If there was continuous voicing from the release of the [d] through the beginning of the stimulus, S_{voi} was not marked.

Nasal-Stop Stimuli

Figure 3.1 illustrates the additional landmarks that were identified in nasal-stop tokens.

Figure 3.1: Production of *anchor* by subject 01 in the sober condition

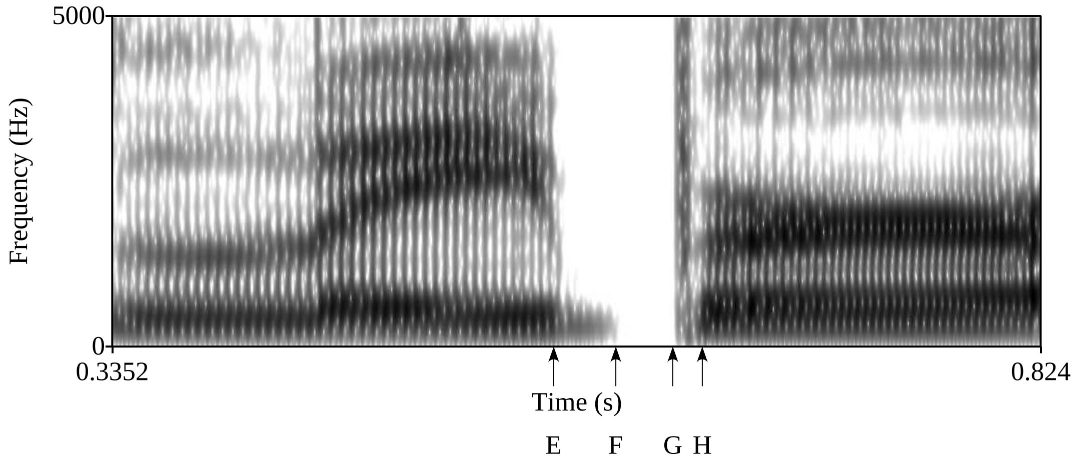


End of vowel (A) The end of the vowel was defined as the beginning of visible antiformants associated with the following nasal. If no antiformants were visible, A was placed at the sharp drop in intensity associated with the closure of the stop.

End of nasal (B) The end of the nasal was defined as the sharp drop in intensity associated with the closure of the stop. B was marked only if it was clearly distinct from both A and C, and if there were no frequencies above 1700 Hz immediately before the closure.

End of voicing (C) The end of voicing was defined as the end of the visible voice bar. In ambiguous cases, I relied on the glottal pulses identified by Praat for guidance.

Figure 3.2: Production of *labor* by subject 01 in the sober condition



Release of consonant (D) The release of the consonant was defined as the vertical dark bar after the closure. If there was no clear release, D was not marked.

Lenition Stimuli

Figure 3.2 illustrates the additional landmarks that were identified in lenition tokens.

Beginning of consonant (E) The beginning of the consonant was defined as the sharp drop in intensity following the preceding vowel.

End of voicing (F) As in the nasal-stop stimuli, the end of voicing was defined as the end of the visible voice bar.

Release of consonant (G) As in the nasal-stop stimuli, the release of the consonant was defined as the vertical dark bar after the closure.

End of consonant (H) The end of the consonant was defined as the first regular glottal striation in the following vowel.

3.3.3 Results

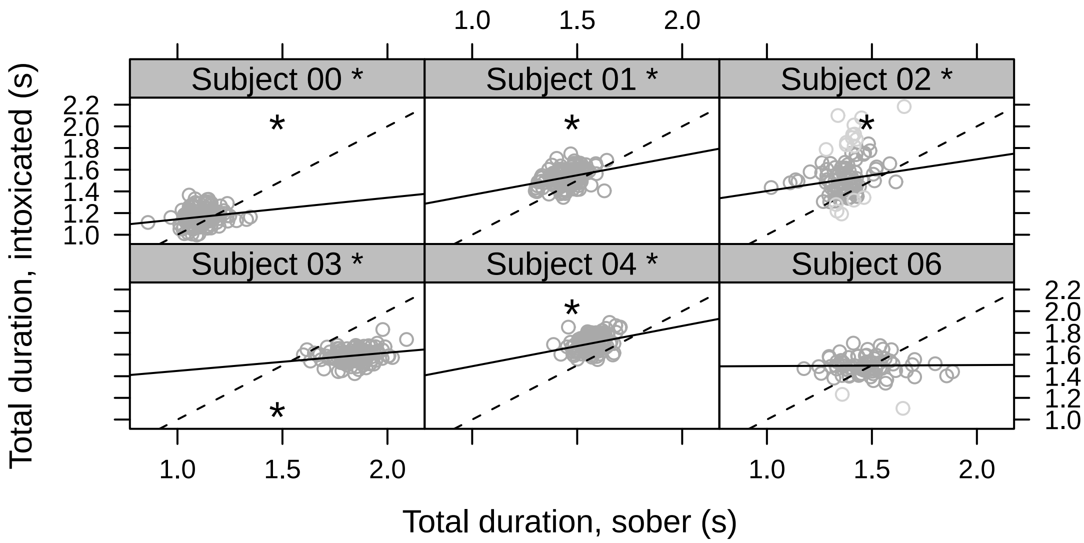
All Stimuli

Duration of frame sentence ($U_f - U_i$). Given the common finding (noted above) that intoxicated speech is slower than sober speech, examining the effect of intoxication on the duration of the entire frame sentence allows us to establish a baseline for comparison with other duration measurements that are more directly relevant to lenition. Recorded tokens were not included from this analysis if they were clipped at either end (because the subject began speaking too early or pressed the space bar before finishing the frame sentence) or if the subject hesitated noticeably during the sentence.

Figure 3.3 shows results for the duration of the frame sentence. Each sub-graph shows results for one subject; subjects 05 and 07 are omitted because too many recordings were clipped to yield a reasonable sample size. Each point represents a single stimulus word; the x-axis shows the duration of the frame sentence for that word in the sober condition, and the y-axis shows the duration in the intoxicated condition, each averaged over two repetitions.

The dotted line in each graph is the line x = y; if alcohol has no effect on the duration of the frame sentence, then the data points should lie along this line. The solid lines represent a linear mixed-effects model predicting intoxicated

Figure 3.3: Duration of frame sentence by subject for nasal-stop and lenition stimuli. Stars next to subject numbers mark subjects with a slope significantly different from 0 and 1 at $\alpha = .05$. Stars at the top or bottom of the graphs mark subjects for whom duration is significantly greater or less, respectively, in the intoxicated condition

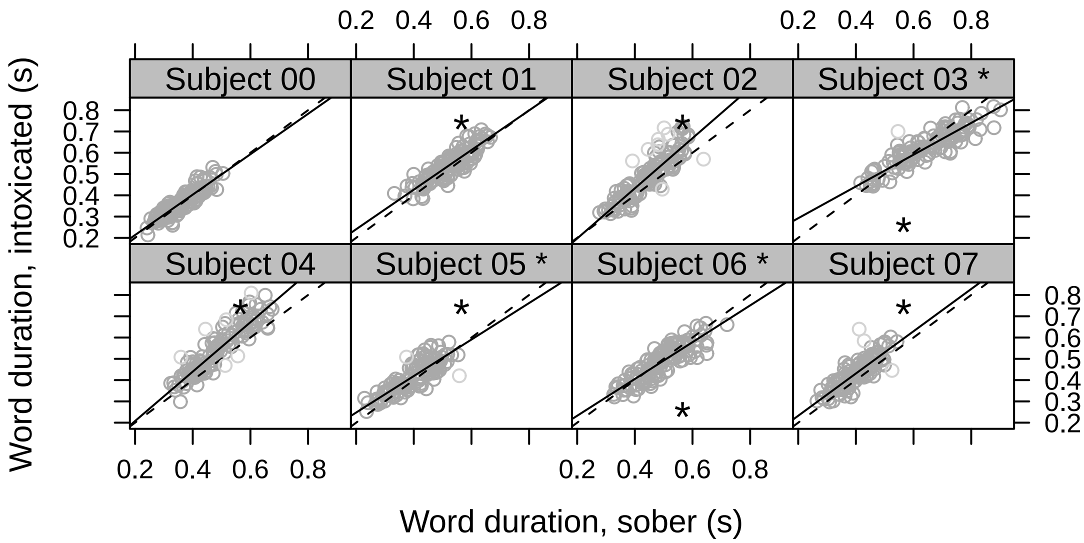


duration from sober duration with by-subject slopes and intercepts. Outliers – defined as data points with residuals more than 2.5 standard deviations from the mean (Baayen 2008, 188-192) – are omitted from the final models and plotted in light gray. A star next to a subject number means that for that subject, the slope of the regression line is significantly greater than 0 and less than 1. A star at the top or bottom of a subject's graph means that for that subject, a paired t-test reveals significantly longer or shorter durations, respectively, in the intoxicated condition. For both tests, the cutoff for significance is $\alpha = .05$. All subsequent graphs in this section have the same layout.

Figure 3.4: Illustration of 'X-pattern'

These results suggest the expected overall pattern of lengthening in the intoxicated condition; subjects 00, 01, 02, and 04 exhibit significantly longer durations in the intoxicated condition. (However, subject 03 shows the opposite pattern, and subject 06 shows no effect.) Note, though, that no subject exhibits *uniform* lengthening in the intoxicated condition. Except for subject 06, all of the subjects display what I will refer to as the 'X-pattern': the slope of the regression line is shallower than 1, and the regression line crosses the line $x = y$ near or within the main grouping of data points. Thus, the 'X-pattern' reveals a tendency whereby, in the intoxicated condition, relatively more time is added to (or removed from) utterances with extreme duration values (that is, very long or very short utterances) than for utterances with less extreme values. When the regression line crosses $x = y$ in the middle of the data, subjects exhibit this avoidance of extreme values at *both* ends of the scale: very long utterances are shortened, and very short utterances are lengthened. Figure 3.4 schematizes how this compression leads to the 'X-pattern'. In other words, subjects appear to exhibit less variance in utterance duration in the intoxicated condition.

Figure 3.5: Duration of stimulus by subject for nasal-stop and lenition stimuli. Stars next to subject numbers mark subjects with a slope significantly different from 0 and 1 at $\alpha = .05$. Stars at the top or bottom of the graphs mark subjects for whom duration is significantly greater or less, respectively, in the intoxicated condition

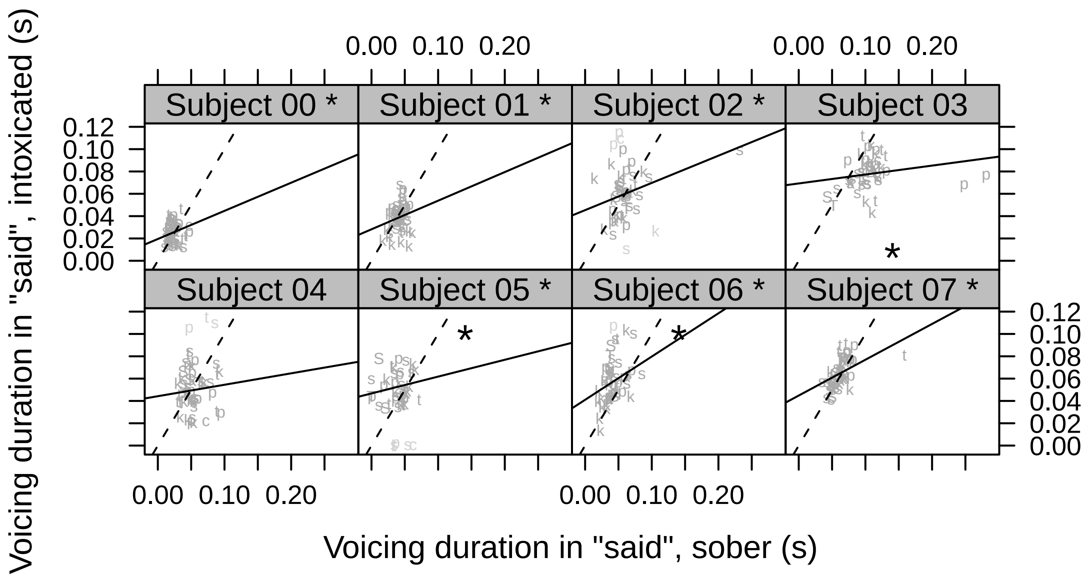


Duration of target word ($W_f - W_i$). Like the duration of the frame sentence, the duration of the target word is relevant to determining whether there is an overall lengthening effect in the intoxicated condition.

Figure 3.5 shows results for the duration of the stimulus word. This measure shows some lengthening in the intoxicated condition relative to the sober condition: duration increases for subjects 01, 02, 04, 05, and 07, but decreases for subjects 03 and 06.

Length of voicing of [d] of *said* ($S_{voi} - S_{clo}$). Word-final devoicing of voiced obstruents is a typologically common process that has been argued to involve

Figure 3.6: Duration of voicing of [d] of *said* by subject for nasal-stop and lenition stimuli. Stars next to subject numbers mark subjects with a slope significantly different from 0 and 1 at $\alpha = .05$. Stars at the top or bottom of the graphs mark subjects for whom duration is significantly greater or less, respectively, in the intoxicated condition



effort reduction (see Westbury and Keating (1986, 156-157), among others). If intoxication encourages final devoicing, then the final voiced [d] of *said* in the frame sentence should have less voicing in the intoxicated condition than in the sober condition. In addition, examining the voicing of the [d] of *said* allows us to distinguish between any effects that intoxication has on postnasal and intervocalic stops from the effects that it has on stops generally. Voicing of the [d] is analyzed only when the target word begins with a voiceless stop or sibilant: before voiced obstruents and sonorants, there is the possibility that the [d] may assimilate in voicing to the following segment, resulting in an *increase* in voicing; before the non-sibilant voiceless fricatives [f], [θ], and [h], the voicing of [d] often continued well into the following segment.

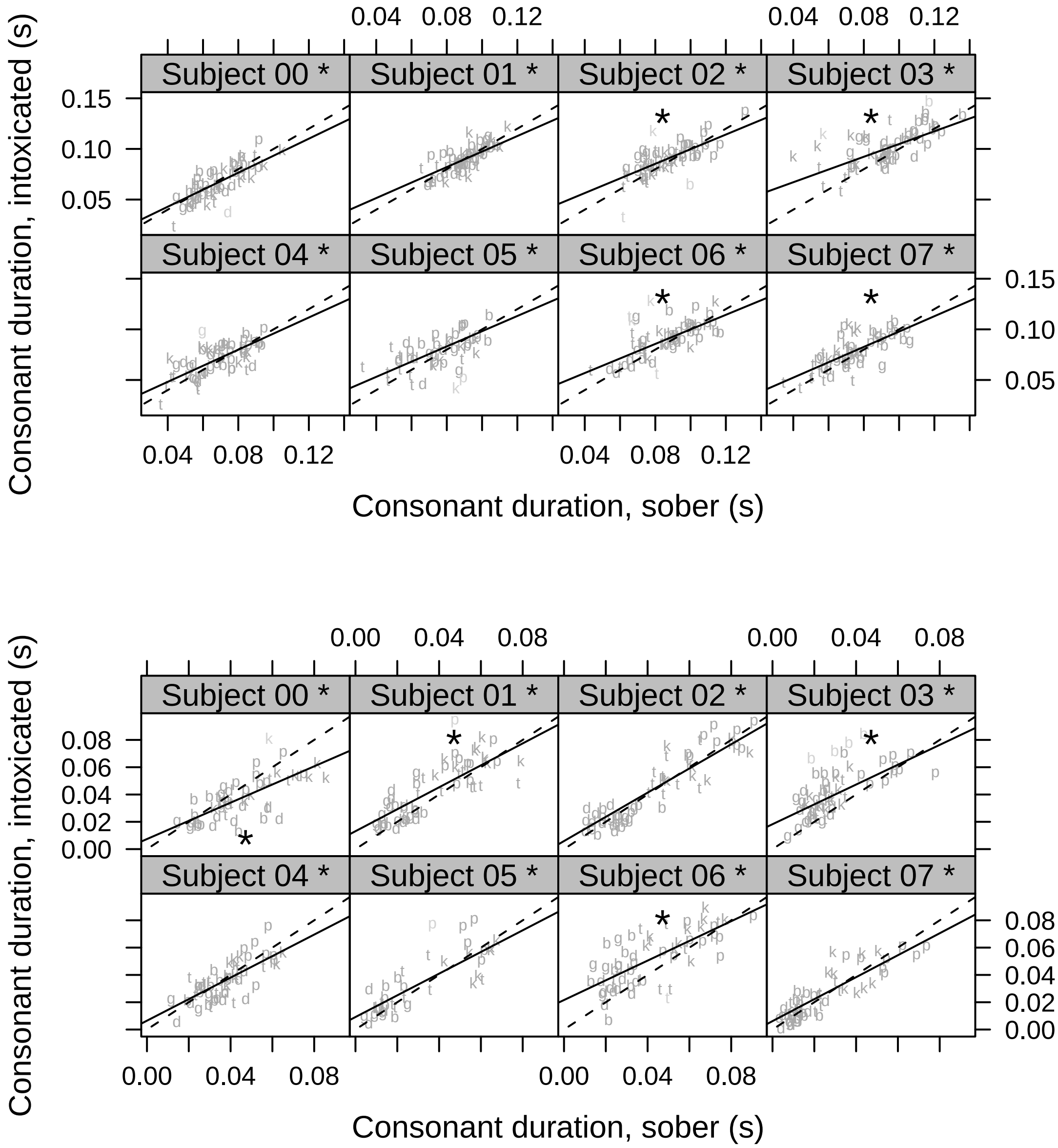
Figure 3.6 shows results for the duration of voicing in the [d] of *said*. The plotting symbol for each point is the initial consonant of the stimulus word; ⟨c⟩ represents [ʧ], and ⟨S⟩ represents [ʃ]. There is no support for an overall pattern of devoicing: subject 03 has decreased voicing in the intoxicated condition, while subjects 05 and 06 have increased voicing. Although several subjects exhibit the 'X-pattern' (00, 01, 02, 05, 06, and 07), two have no significant correlation between voicing durations in the two conditions (03 and 04). This weak result is not surprising, given the fact that utterances are paired across conditions by the stimulus word. We expect the duration of the word to be highly dependent on the identity of the word, and, thus, we should find a strong correlation between the duration of the word in the sober and intoxicated conditions. However, the identity of the word is likely to have a smaller effect on the voicing of the final consonant of the word that immediately precedes it; thus, the correlations between the sober and intoxicated conditions are weaker.

Nasal-Stop Stimuli

Duration of consonant. Voiceless obstruents tend to be longer than voiced obstruents (Kingston and Diehl 1994, 441). If intoxication encourages postnasal voicing, then consonants should be shorter in the intoxicated condition. Consonant duration was calculated in two ways: from the end of the vowel ($D - A$), and from the end of the nasal, if present ($D - B$).

Figure 3.7 shows results for the duration of the consonant, as measured from the end of the vowel (top graph) and from the end of the nasal (bottom graph).

Figure 3.7: Duration of consonant from end of vowel (top) and nasal (bottom) by subject for nasal-stop stimuli. Stars next to subject numbers mark subjects with a slope significantly different from 0 and 1 at $\alpha = .05$. Stars at the top or bottom of the graphs mark subjects for whom duration is significantly greater or less, respectively, in the intoxicated condition



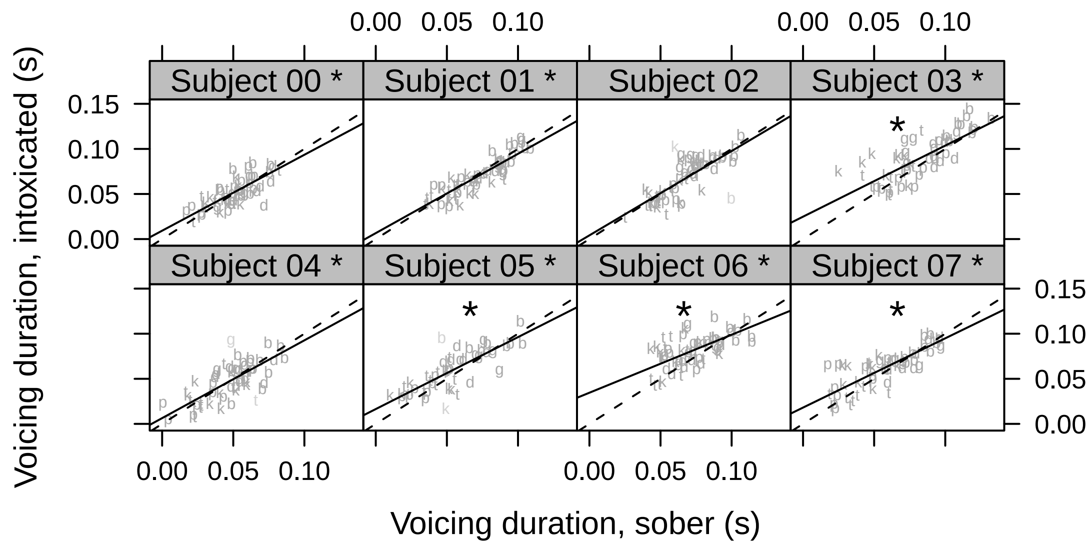
The plotting symbol is the stop in the nasal-stop sequence of the stimulus word. As was the case for the two global duration measures considered above, there appears to be a general trend of lengthening in the intoxicated condition; only subjects 00, 04, and 05 fail to exhibit a significant increase in consonant duration for at least one measurement. The 'X-pattern', where the regression lines have a slope shallower than 1, is consistent across subjects and measurements.

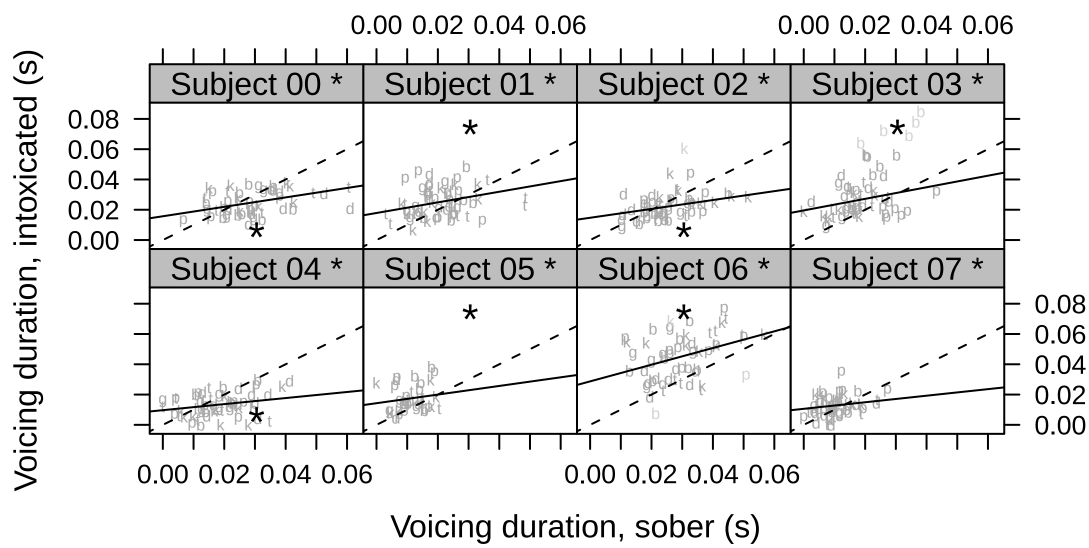
This lengthening effect is *not* consistent with postnasal voicing. However, it is possible that the lengthening seen here is not due to postnasal devoicing in the intoxicated condition, but rather to the overall lengthening of intoxicated speech.

Duration of voicing. If intoxication encourages postnasal voicing, then voicing should increase in the intoxicated condition. As for overall duration, voicing duration was calculated in two ways: from the end of the vowel ($C-A$), and from the end of the nasal, if present ($C-B$). In each case, if the consonant was fully voiced, then voicing duration was measured up to the release of the consonant (D).

Figure 3.8 shows results for the duration of voicing. For both measures, four subjects exhibit significantly increased voicing. When voicing is measured from the end of the nasal, the remaining three subjects exhibit decreased voicing; when voicing is measured from the end of the vowel, the remaining three subjects show no effect. Because a large number of recorded tokens contained fully voiced consonants (as shown by the clustering of data points for voicing proportion in figure 3.9 around 1), it is likely that these results are parasitic on the effect of intoxication on overall consonant length. Note that in most cases, a subject who shows a significant increase or decrease in voicing duration in the intoxicated condition for some measure *also* shows an increase or decrease in consonant duration for the

Figure 3.8: Duration of voicing from end of vowel (top) and nasal (bottom) by subject for nasal-stop stimuli. Stars next to subject numbers mark subjects with a slope significantly different from 0 and 1 at $\alpha = .05$. Stars at the top or bottom of the graphs mark subjects for whom duration is significantly greater or less, respectively, in the intoxicated condition





corresponding measure. In addition, no subject shows a significant effect in one direction for consonant duration and in another direction for voicing duration.

Proportion of consonant that is voiced. Since intoxication appears to have a slight lengthening effect on consonant duration, any increase in voicing duration may be due solely to the change in consonant length, and not to a change in subjects' propensity to produce voicing. Measuring voicing in terms of the proportion of the consonant that is voiced is one way to factor out the effect of overall consonant length. As above, voicing proportion was calculated in two ways: from the end of the vowel ($\frac{C-A}{D-A}$), and from the end of the nasal, if present ($\frac{C-B}{D-B}$).

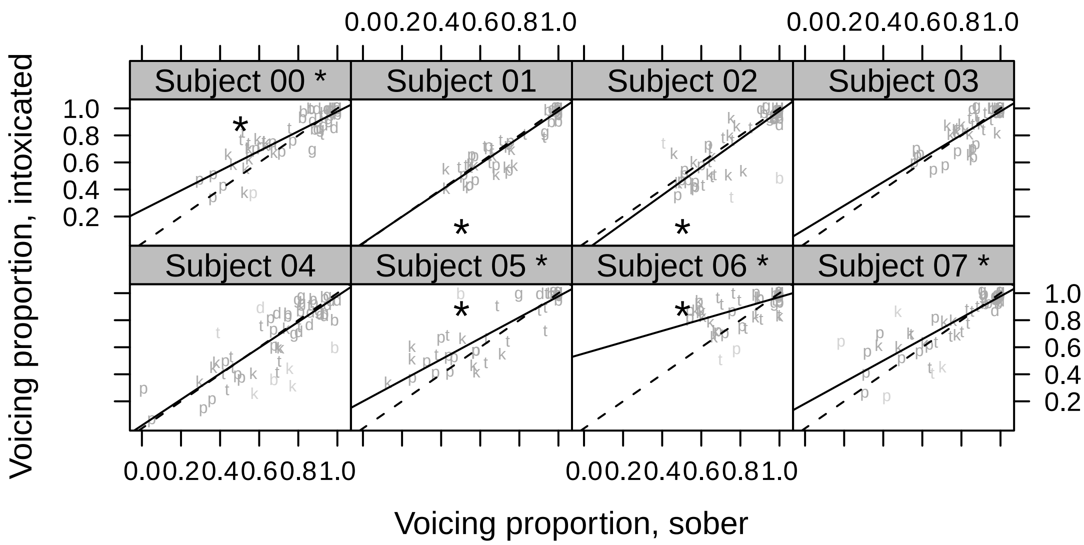
Figure 3.9 shows results for voicing proportion. Although linear models were fitted to these results as to the others, they are not entirely appropriate since the dependent variable, a proportion, is bounded by 0 and 1; thus, the 'X-pattern' exhibited for voicing measured from the end of the nasal may not be reliable. Only a few subjects show a consistent change in voicing proportion in the intoxicated condition, and the direction of the change is not consistent (an increase in some cases, a decrease in others). This measure, therefore, does not provide evidence that there was an overall change in the amount of voicing in the intoxicated condition.

Lenition Stimuli

Duration of consonant ($G - E$). If intoxication encourages intervocalic voicing, then consonants should be shorter in the intoxicated condition. Duration was calculated to the release of the consonant, as with the nasal-stop stimuli.

Figure 3.10 shows results for consonant duration. There appears to be a

Figure 3.9: Proportion of closure that is voiced from end of vowel (top) and nasal (bottom) by subject for nasal-stop stimuli. Stars next to subject numbers mark subjects with a slope significantly different from 0 and 1 at $\alpha = .05$. Stars at the top or bottom of the graphs mark subjects for whom duration is significantly greater or less, respectively, in the intoxicated condition



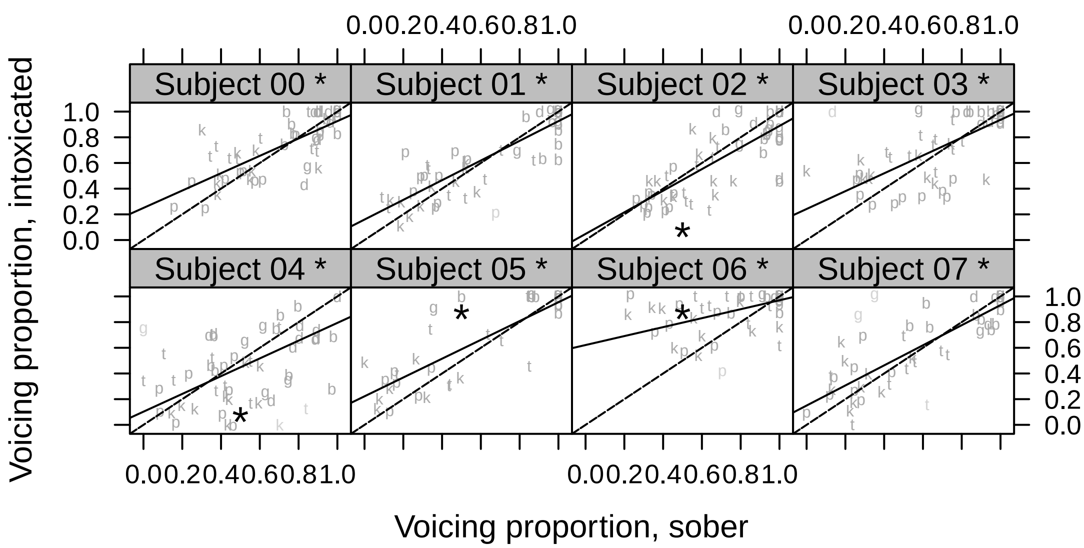
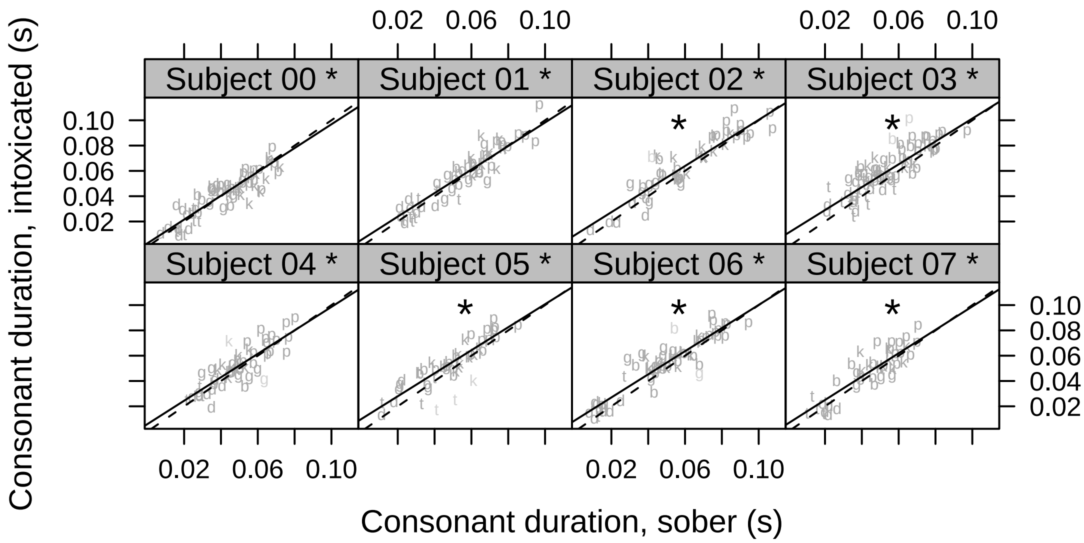


Figure 3.10: Duration of consonant by subject for lenition stimuli. Stars next to subject numbers mark subjects with a slope significantly different from 0 and 1 at $\alpha = .05$; stars at the top or bottom of the graphs mark subjects for whom duration is significantly greater or less, respectively, in the intoxicated condition

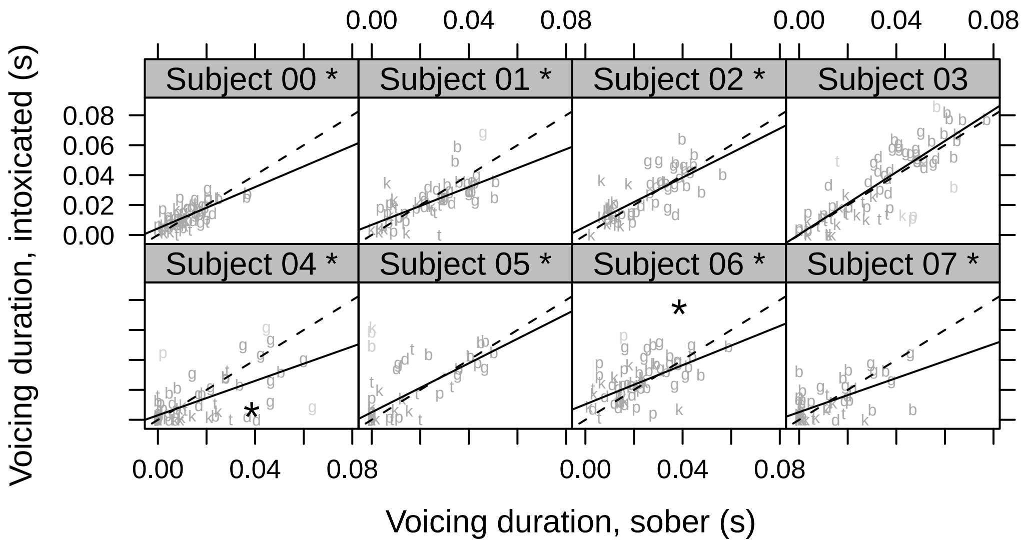


lengthening effect; five subjects (02, 03, 05, 06, and 07) show significantly increased duration in the intoxicated condition, and no subject has the opposite effect. Stronger and more consistent, though, is the 'X-pattern' noted above: the regression line for every subject has a slope between 0 and 1 (and significantly different from either).

Duration of voicing ($F-E$). If intoxication encourages intervocalic voicing, then voicing should increase in the intoxicated condition. As for nasal-stop stimuli, if the consonant was fully voiced, voicing was measured to the release (G).

Figure 3.11 shows results for voicing duration. There appears to be no overall shift in voicing duration in the intoxicated condition; only two subjects have a

Figure 3.11: Duration of voicing by subject for lenition stimuli. Stars next to subject numbers mark subjects with a slope significantly different from 0 and 1 at $\alpha = .05$; stars at the top or bottom of the graphs mark subjects for whom duration is significantly greater or less, respectively, in the intoxicated condition



significant effect (in different directions). However, every subject except subject 03 exhibits a significant 'X-pattern': highly voiced consonants become slightly less voiced in the intoxicated condition, and consonants with very little voicing acquire slightly more. Subjects in the intoxicated condition appear to avoid extreme values of voicing at either end of the spectrum, and instead favor intermediate voicing durations.

Proportion of consonant that is voiced ($\frac{F-E}{G-E}$). As with the nasal-stop stimuli, voicing during the consonant was also calculated in terms of the proportion of the consonant that is voiced, in order to factor out the effect of changes in overall consonant length.

Figure 3.12: Proportion of closure that is voiced by subject for lenition stimuli. Stars next to subject numbers mark subjects with a slope significantly different from 0 and 1 at $\alpha = .05$. Stars at the top or bottom of the graphs mark subjects for whom duration is significantly greater or less, respectively, in the intoxicated condition

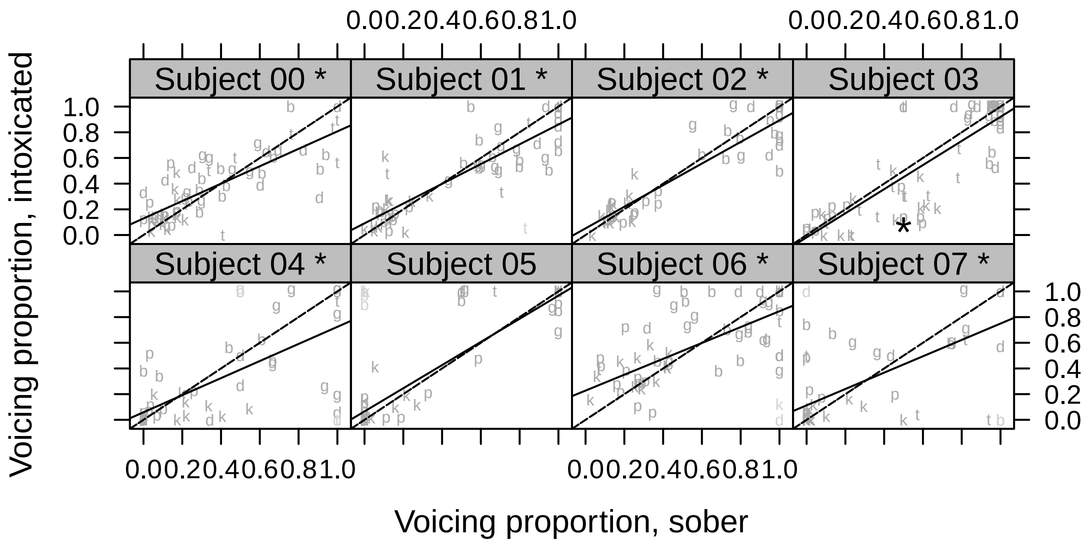
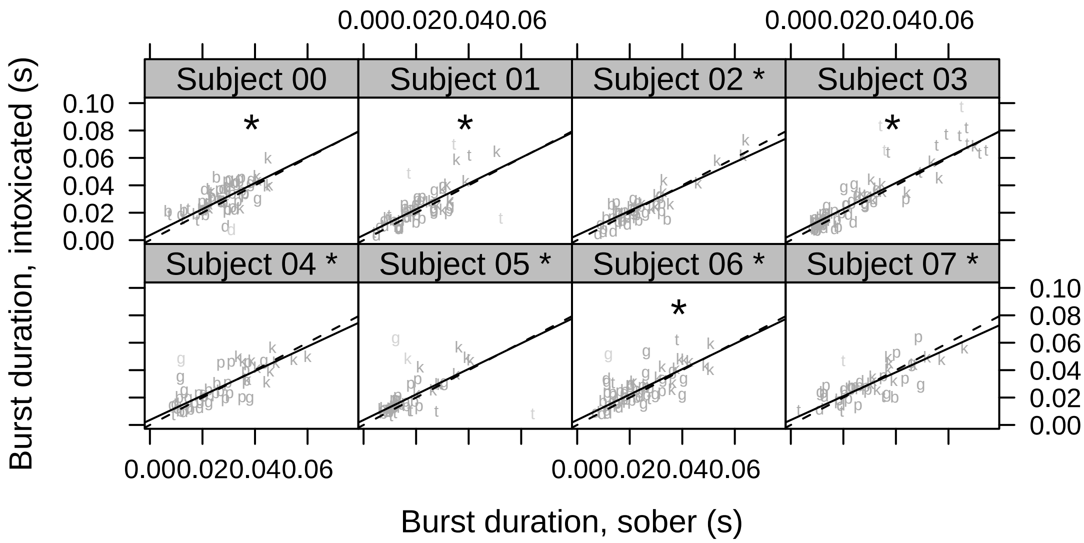


Figure 3.12 shows results for voicing proportion. Only subject 03 exhibits a change in overall voicing in the intoxicated condition (a slight decrease); all other subjects except subject 05 have the 'X-pattern' but no general shift in the amount of voicing during the consonant. Thus, this measure does not support a pattern of intervocalic voicing.

Duration of burst ($H - G$). The duration of the consonant's burst and any subsequent aspiration (referred to here simply as "burst duration") is longer for voiceless stops than for voiced stops. (In English, the extra duration for voiceless stops is due at least in part to the aspiration that follows them, even in intervocalic

Figure 3.13: Duration of burst by subject for lenition stimuli. Stars next to subject numbers mark subjects with a slope significantly different from 0 and 1 at $\alpha = .05$. Stars at the top or bottom of the graphs mark subjects for whom duration is significantly greater or less, respectively, in the intoxicated condition

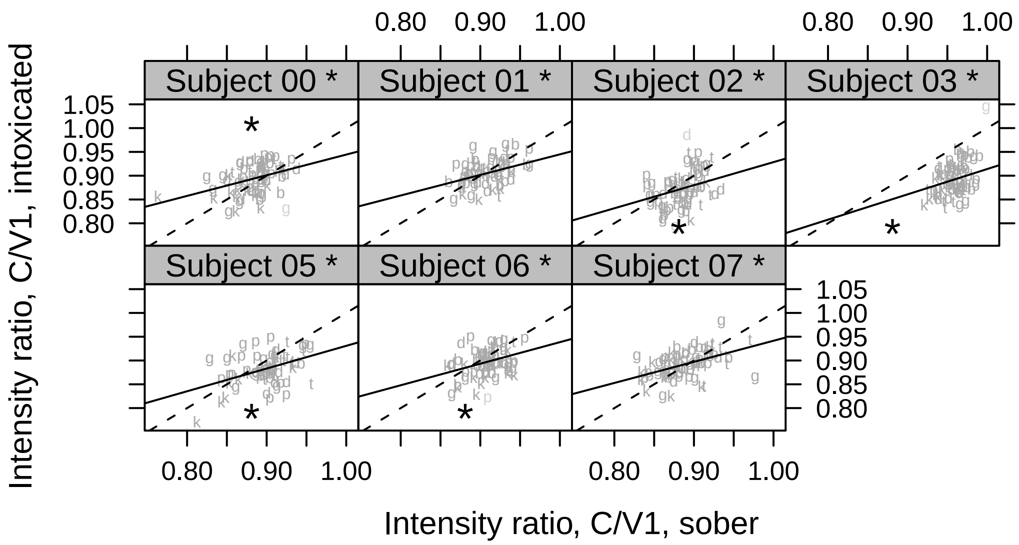


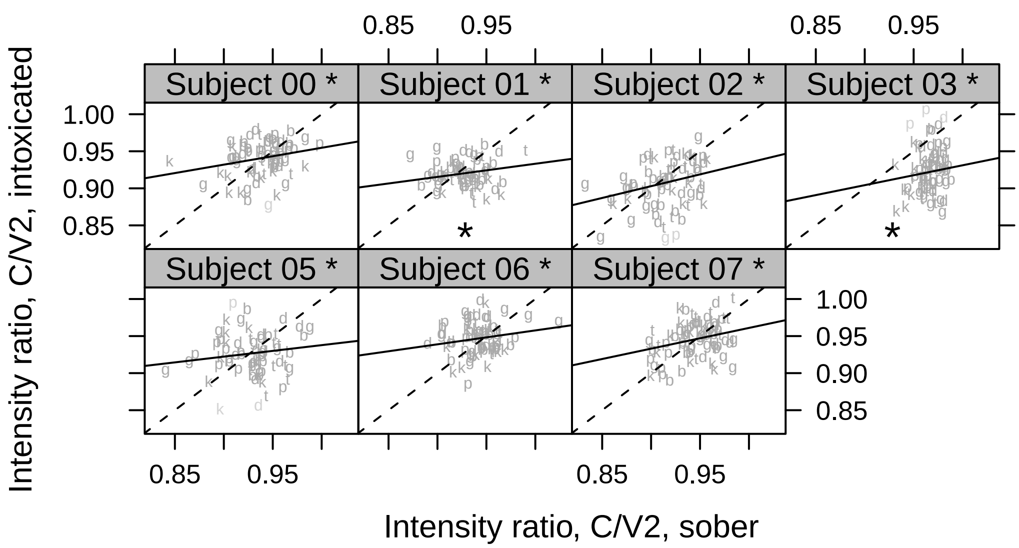
position, as noted in the discussion of the stimuli for Experiment 2. As shown in table 5.1 below, burst duration differed significantly between voiced and voiceless stops for all subjects in Experiment 1 except subject 00.) Thus, we expect burst duration to decrease in the intoxicated condition.

Figure 3.13 shows results for burst duration. Four subjects show *increased* burst duration in the intoxicated condition (00, 01, 03, and 06); five show the 'X-pattern' (02, 04, 05, 06, and 07). Burst duration does not support a pattern of intervocalic voicing in the intoxicated condition; if anything, it suggests a change in the opposite direction.

Ratio of minimum intensity in consonant to maximum intensity in

Figure 3.14: Ratio of intensity of consonant to preceding vowel (top) and following vowel (bottom) by subject for lenition stimuli. Stars next to subject numbers mark subjects with a slope significantly different from 0 and 1 at $\alpha = .05$. Stars at the top or bottom of the graphs mark subjects for whom the ratio is significantly greater or less, respectively, in the intoxicated condition



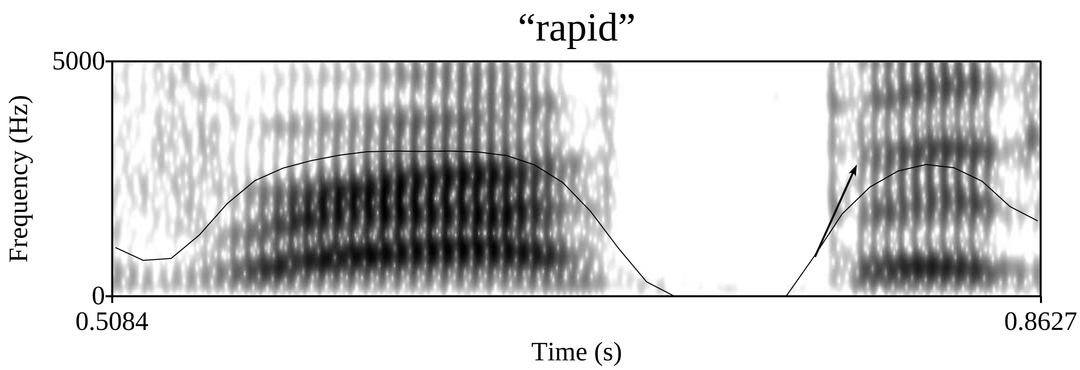


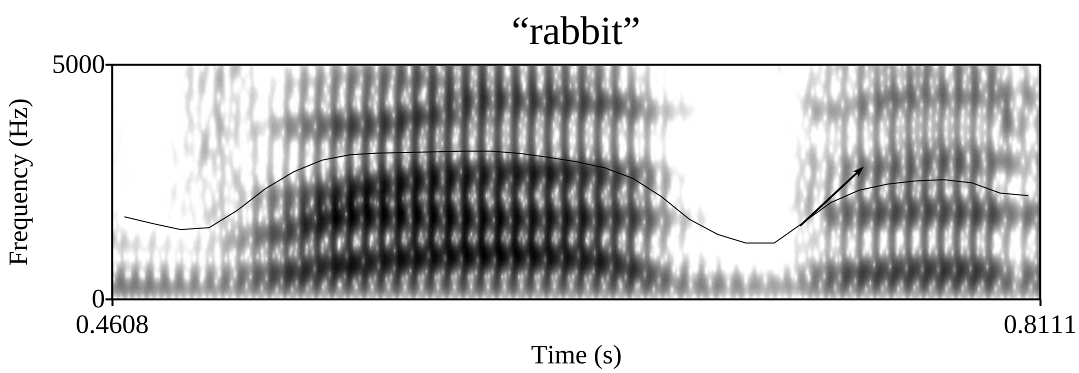
vowel. Voiced stops are expected to be more intense than voiceless stops during closure because of the energy added by the voicing component; spirants are expected to be more intense than stops because of the energy added by the turbulent airflow of frication. If intoxication encourages intervocalic voicing or spirantization, the intensity of the consonant should increase in the intoxicated condition. With this measure, the intensity of the consonant (represented by the minimum intensity during the consonant closure) is relativized to the maximum intensity of the preceding or following vowel. For this measure, and for all subsequent measures involving intensity, subject 04 is omitted: this subject's recordings had significant clipping in the sober condition.

Figure 3.14 shows results for intensity ratios relative to the preceding vowel (top graph) and following vowel (bottom graph). Although subject 00 has increased consonant intensity relative to the preceding vowel in the intoxicated condition, there is no other significant increase in consonant intensity, and there are several significant decreases. Thus, these measures provide no evidence for an overall pattern of intervocalic voicing or spirantization in the intoxicated condition. The 'X-pattern', on the other hand, is significant for every subject for both measures: in the intoxicated condition, subjects avoid both very intense consonants and very quiet ones.

Smallest/largest slope of intensity contour in consonant. Another measure of the intensity of the consonant relative to the surrounding vowels involves the slope of intensity contour (Kingston 2008). The quieter the consonant, the steeper the slope of the contour will be leading into and out of the consonant (because of the large transition between the loud vowel and the quiet consonant); conversely, the more intense the consonant, the shallower the slope will be. We

Figure 3.15: Intoxicated production of *rapid* (top) and sober production of *rabbit* (bottom) by subject 02, with intensity contours; arrows show maximum slope of intensity contour during consonant

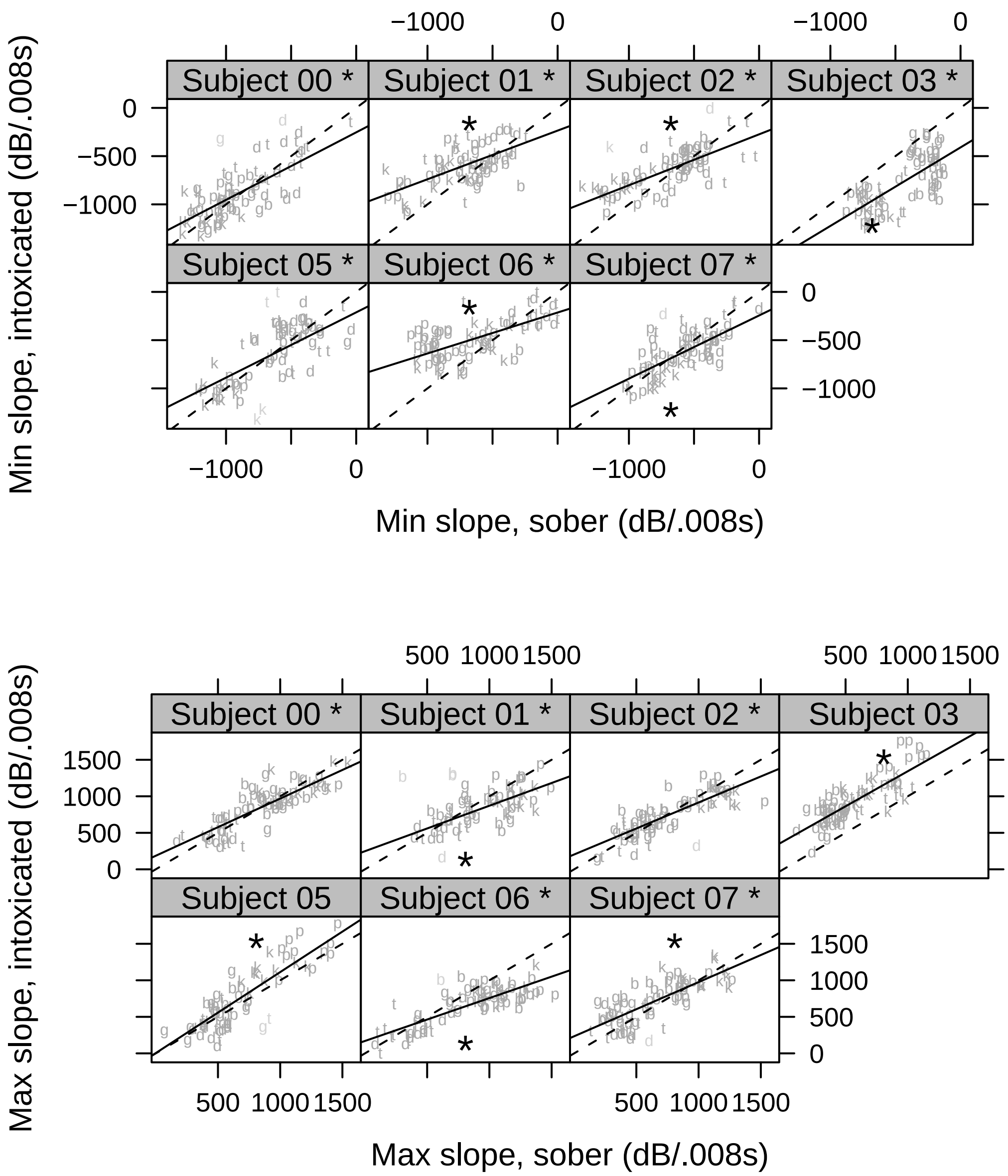




can get a global measure of the slope of the intensity contour leading into the consonant by finding its smallest (most negative) slope; similarly, we can measure the slope leading out of the consonant by finding its largest slope. (See figure 3.15 for an illustration.) If intoxication induces intervocalic voicing or spirantization, then each measure should be significantly closer to zero in the intoxicated condition.

Figure 3.16 shows results for minimum (top graph) and maximum (bottom graph) slopes of the intensity contour. There is no general pattern in terms of an

Figure 3.16: Minimum (top) and maximum (bottom) slope of intensity contour during consonant by subject for lenition stimuli. Stars next to subject numbers mark subjects with a slope significantly different from 0 and 1 at $\alpha = .05$. Stars at the top or bottom of the graphs mark subjects for whom the slope is significantly greater or less, respectively, in the intoxicated condition



overall shift in the intoxicated condition: for each measure, some subjects have significant increases, while others have significant decreases. These measures, like most of those before them, do not support a pattern of intervocalic voicing or spirantization. The ‘X-pattern’, however, remains robust: with only two exceptions (subjects 03 and 05 for maximum slope), the regression lines uniformly have a slope between 0 and 1.

3.3.4 Discussion

Overall Results

Table 3.2 summarizes significant results for each of the measures discussed above. For each subject and each measure, there are two possible significant effects. The first is whether the subject displays the ‘X-pattern’ for that measure: that is, whether the slope of the regression line for that subject is significantly less than 1 (but greater than 0). Subjects with this pattern appear to avoid ‘extreme’ articulations at one or both ends of the relevant scale, and to favor instead productions with intermediate values. For example, for subject 06, if a consonant in one of the lenition stimuli had a great deal of voicing in the sober condition as measured by proportion of the closure that was voiced, then that consonant in the same stimulus in the intoxicated condition tended to have slightly less voicing. But if a consonant had very little voicing in the sober condition, then it tended to have slightly more in the intoxicated condition. Significant ‘X-patterns’ are shown with gray cells.

The second type of significant effect is an overall difference in the measured quantity between the two conditions, as determined by a paired t-test. Subjects

Table 3.2: Summary of significant effects. A gray cell denotes a regression line with a slope significantly different from 0 and 1. An arrow denotes a significant difference between the sober and intoxicated conditions as determined by a paired t-test. The direction of the arrow shows whether the value increased or decreased in the intoxicated condition; a double arrow shows an effect in the expected direction, a single arrow the opposite direction

Measure	**Subject**							
	00	**01**	**02**	**03**	**04**	**05**	**06**	**07**
All Stimuli								
Dur. frame sentence	⇑	⇑	⇑	↓	⇑			
Dur. stimulus		⇑	⇑	↓	⇑	⇑	↓	⇑
Dur. voicing in *sai*[d]				⇓		↑	↑	
Nasal-Stop Stimuli								
Dur. consonant (from V)			↑	↑			↑	↑
Dur. consonant (from N)	⇓	↑		↑			↑	
Dur. voicing (from V)				⇑		⇑	⇑	⇑
Dur. voicing (from N)	↓	⇑	↓	⇑	↓	⇑	⇑	
Prop. closure voiced (from V)	⇑	↓	↓			⇑	⇑	
Prop. closure voiced (from N)			↓		↓	⇑	⇑	
Lenition Stimuli								
Dur. consonant			↑	↑		↑	↑	↑
Dur. voicing					↓		⇑	
Prop. closure voiced				↓				
Dur. burst	↑	↑		↑			↑	
Int. ratio, C/V1	⇑		↓	↓		↓	↓	
Int. ratio, C/V2		↓		↓				
Min. slope, int. contour		⇑	⇑	↓			⇑	↓
Max. slope, int. contour		⇓		↑		↑	⇓	↑

with this pattern display an overall preference for one end of the scale over the other in the intoxicated condition. For example, subject 03 had more intense consonants in the intoxicated condition, as measured by the maximum slope of the intensity contour during the consonant, than in the sober condition. Significant differences of this type are shown with an arrow. The direction of the arrow shows whether the measured value increased (up) or decreased (down) in the intoxicated condition. The shape of the arrow shows whether the change was in the expected direction (that is, the direction corresponding to intervocalic voicing/spirantization, postnasal voicing, or final devoicing): double arrows show expected changes, and single arrows unexpected ones. For the overall duration of the frame sentence and the stimulus word, neither change is necessarily predicted by the sound patterns under consideration; for these measures, the 'expected' change (as marked in the table) is an increase in duration, given previous findings in the literature that intoxication leads to slower speech.

Note that these two patterns are not mutually exclusive: it is possible for a subject to display the 'X-pattern' in addition to an overall preference for one end of the scale over the other for the same measure. For example, subject 06 shows longer consonants (measured from the end of the nasal) in the nasal-stop stimuli in the intoxicated condition. However, the effect is strongest for those stimuli whose consonants are very short in the sober condition; for stimuli whose consonants are already very long in the sober condition, there is little or no increase in the intoxicated condition. In other words, the range of consonant duration that subject 06 is willing to produce is smaller in the intoxicated condition than in the sober condition, even though the midpoint of that range is relatively high compared to the range in the sober condition.

Table 3.2 provides little, if any, support for the prediction that intoxicated speech mirrors attested phonological patterns. Significant changes in the intoxicated condition that correspond to the attested patterns of intervocalic voicing and spirantization, postnasal voicing, or final devoicing are few and far between, and a change in the expected direction for one subject is almost always accompanied by a change in the opposite direction for that measure for some other subject. This is the case even if we disregard all of the measures based on duration, where the general lengthening of intoxicated speech may be a confounding factor.

The pattern for which table 3.2 provides strong support is the 'X-pattern': when intoxicated, subjects are less willing to make 'extreme' productions. There are only a handful of cases where this pattern is *not* significant. Thus, the articulatory space of intoxicated subjects appears to be compressed; rather than (or in addition to) favoring one end of the scale over the other, subjects are reverting to gestures in the middle of the articulatory space.

The recurrent 'X-pattern' is consistent with the idea that intoxicated subjects expend less effort. If extreme gestures require more effort to produce than gestures in the middle of the articulatory space, then the compression of the articulatory space observed in the intoxicated condition means that subjects expended less effort after drinking alcohol than they did while they were sober. As discussed in chapter 5, there are in fact a number of proposals in the phonological literature linking articulatory effort with the extremes of the articulatory space; thus, the results of this experiment speak directly to particular theories of the relationship between articulatory effort and phonological patterns.

Effect of BAC

If the primary effect of alcohol on production is to cause contraction of the articulatory space, then we might expect higher levels of intoxication to cause more contraction. Because BAC varied both within and across subjects during Experiment 1 (as shown in table 3.1), it is possible the data could provide us with evidence for such an effect.

I used the within-subject variation in BAC to determine whether there was a within-subject effect of BAC on the degree of articulatory contraction. Each recording session was divided into two parts: the first half of the trials (containing the first repetition of each stimulus word) and the second half (containing the second repetition). The initial and final BAC measures for each subject were used as a rough approximation of that subject's BAC during the first and second halves of the intoxicated recording session, respectively.

As above, for each measure of lenition, I built a linear mixed-effects model predicting values in the intoxicated condition from values in the sober condition. Productions from the first half of the intoxicated recording session for each subject were paired with productions from the first half of the sober recording session for the same subject; productions from the second half of each session were paired in the same way. Each model includes random slopes and intercepts for each half of the recording session for each subject. If higher BACs do indeed cause greater contraction of the articulatory space, then the slope of the regression line should be systematically smaller for the half of the recording session in which a given subject had a higher BAC, and larger for the other half of the recording sesion for the same subject.

As it turns out, there is no systematic difference in slope between subjects' productions with higher or lower BACs. A paired t-test of the slope of the regression line for all measures and subjects reveals no significant difference between more and less intoxicated parts of the recording session ($p = .71$). However, there are several reasons not to be surprised at this null result:

- The within-subject differences in BAC are very small (usually between .01 and .03).

- For most subjects, BAC was higher at the beginning of the recording session; for subjects 04 and 07, BAC was higher at the end. It is possible that there are independent effects of timing within each session that are masking any effects of relative BAC.

- Although we know each subject's BAC at the beginning and end of the experiment, we do not know what trajectory the subject's BAC took *during* the recording session. For example, subject 00 began the intoxicated recording session with a BAC of .10 and ended it with a BAC of .07. However, we do not know whether the subject peaked at .10 and experienced a monotonic decline in BAC during the session, or whether the subject peaked later during the session and only then experienced a drop in BAC. Thus, beginning and ending BAC give us only a rough approximation of subjects' BAC throughout the recording session.

- For subjects 04 and 07, who had a higher BAC at the end of the session than at the beginning, we do not know whether they peaked during or after the recording session – that is, whether the value measured at the end of the session was on the rising or falling side of the BAC curve. This difference is important because of the phenomenon known as the Mellanby effect, whereby perforance of intoxicated subjects is more impaired while BAC is rising than it is at same BAC when BAC is falling (Wang et al. 1993).

Thus, although a post-hoc analysis of the effects of variation in BAC in Experiment 1 provides no evidence that higher BACs lead to greater contraction of the articulatory space, it is possible that an experiment specifically designed to answer this question would find an effect.

3.4 Conclusion

Experiment 1 was designed to determine whether intoxication – hypothesized to induce subjects to expend less articulatory effort – results in productions that resemble certain phonological patterns that have been claimed to involve effort reduction, including final devoicing, postnasal voicing, and intervocalic voicing and spirantization. The results of the experiment show that subjects did *not* systematically alter their productions when intoxicated in a manner corresponding to these patterns; instead, the most robust effect observed was a compression of the articulatory space in the intoxicated condition. Although there is no guarantee that alcohol consumption does in fact encourage subjects to expend less articulatory effort, the articulatory compression that they exhibit is plausibly interpreted as effort reduction and should not be lightly dismissed. Chapter 5 considers the implications of these results both for phonological theories of articulatory effort and for our account of lenition patterns in particular.

Chapter 4

Perception of Intervocalic Voicing and Spirantization

This chapter reports the results of three experiments that were designed to explore the possible role of perception in the lenition of intervocalic stops. As discussed in the introduction, the potential effect of perceptual factors on lenition has received little attention in the literature, Kingston (2008) being a recent exception. The particular perceptual model that I examine is the P-map (Steriade 2001a,b).

Recall the basic typological fact I intend to account for – that spirantization of intervocalic voiceless and voiced stops (as in (1)) and voicing of intervocalic voiceless stops (as in (2a)) are attested, while devoicing of intervocalic voiced stops (as in (2b)) is not.

(1) a. **Attested:** Intervocalic voiceless stops targeted for spirantization

(e.g., Tiberian Hebrew)

(i) /VpV/ → [VɸV]

(ii) /VtV/ → [VθV]

(iii) /VkV/ → [VxV]

b. **Attested:** Intervocalic voiced stops targeted for spirantization *(e.g., Spanish)*

(i) /VbV/ → [VβV]

(ii) /VdV/ → [VðV]

(iii) /VgV/ → [VɣV]

(2) a. **Attested:** Intervocalic voiceless stops targeted for voicing *(e.g., Warndarang)*

(i) /VpV/ → [VbV]

(ii) /VtV/ → [VdV]

(iii) /VkV/ → [VgV]

b. **Unattested:** Intervocalic voiced stops never targeted for devoicing

(i) */VbV/ → [VpV]

(ii) */VdV/ → [VtV]

(iii) */VgV/ → [VkV]

The P-map (Steriade 2001a,b) builds on the ideas of Licensing by Cue to provide a framework for a perceptually-based understanding of typological gaps such as the absence of patterns like (2b). The core intuition of Steriade's proposal is that "[t]he aim, in any departure from the UR, is to change it *minimally* to achieve compliance with the phonotactics" (Steriade 2001a, 4). She formalizes this notion of minimality in terms of perceptibility: form A is 'closer' to form B than form C is if the A ∼ B distinction is perceptually less salient than the C ∼ B distinction, where perceptual salience is defined as mutual confusability. Knowledge of the relative perceptibility of various contrasts (however it may be manifested in actual listeners) is known as the P-map.

For example, final voiced stops are often targeted for devoicing, but never for being turned into sonorants. Steriade proposes that the latter repair is never employed because the contrast between voiced and voiceless obstruents is less perceptible in the environment V__# than the contrast between voiced obstruents and sonorants. In other words, final voiced obstruents undergo the 'smallest' change possible, where the size of a change is defined in perceptual terms. The P-map has also been used to explain phenomena such as asymmetries in consonant assimilation and the types of segments that are epenthesized (Steriade 2001b), the behavior of voicing in singleton and geminate stops (Kawahara 2006), and laryngeal co-occurrence restrictions (Gallagher 2009).

Under this approach, the explanation for the absence of intervocalic devoicing would be that devoicing is a more perceptible repair to intervocalic voiced stops than spirantization. The results of Experiments 2 – 4 have implications both for the P-map and for the traditional articulatory understanding of lenition. To the extent that the results allow the P-map to make the desired predictions, we have evidence that perception by itself is enough to account for the relevant typological patterns; it then becomes superfluous to invoke articulatory effort as an additional explanation for the same facts in the absence of more direct evidence that effort is involved. Although the sufficiency of a perceptual explanation does not completely rule out a role for articulation since a typological pattern may have multiple overlapping causes, it does mean that the purported role of articulation must be more thoroughly tested (as in chapter 3). In addition, such a result constitutes evidence in support of the P-map itself as an approach to explaining typological patterns (although not to the exclusion of other perceptual approaches; there are other models of phonological patterns that can achieve similar results).

On the other hand, to the extent that the results do *not* provide a perceptual explanation along the lines of the P-map for the relevant typological facts, we have evidence that other influences must be at work. One notable example is the fact that the P-map is meant to explain not *why* a given configuration is changed – in Optimality-Theoretic terms (Prince and Smolensky 2004[1993]), this is the role of markedness constraints – but rather *how* it changes (the role of faithfulness constraints). Thus, perception may not tell us anything at all about whatever markedness constraint drives languages to lenite in the first place; I return to this point in §5.1.

As the results of Experiment 2 show, intervocalic devoicing is a *more* perceptible change than intervocalic spirantization; by contrast, Experiment 4 shows that spirantization and voicing of voiceless stops are about equally perceptible. Therefore, the approach of the P-map seems to be on the right track in explaining the broad typology of (1) and (2). However, we will see from the results of Experiment 3 that for voiced stops, the perceptual facts differ by place of articulation in ways that do not line up neatly with the typology discussed in §2.2. Thus, while perceptual facts may be able to explain the broad outlines of intervocalic lenition, there must be other factors at work as well.

4.1 Experiment 2: Relative Perceptibility of Devoicing and Spirantization for Voiced Stops

Experiment 2 was designed to test the relative perceptibility of two logically possible repairs for intervocalic voiced stops: devoicing and spirantization. The experiment compares voiced stops at each of the three major places of articulation ([b], [d], [g]) in terms of mutual confusability with their voiceless counterparts on the one hand and spirant counterparts on the other, with the goal of determining which series is more confusable with voiced stops.

4.1.1 Design

Recording of Stimuli

Table 4.1: Perceptibility comparisons in Experiments 1 and 2

	[+voi] Spirants		[+voi] Stops		[−voi] Stops
Labials	β	∼	b	∼	p
Coronals	ð	∼	d	∼	t
Dorsals	ɣ	∼	g	∼	k
Cover Symbol	**Z**	∼	**D**	∼	**T**

The stimuli for the experiment consisted of each of the nine consonants listed in table 4.1 recorded in the environment [a___a]. Tokens were recorded by five talkers: two native speakers of Spanish (talkers 4 and 5) and three native speakers of English (talkers 1 – 3). Spanish speakers were used because Spanish has a variant of the spirantization pattern; thus, their productions of the [aZa] tokens should accurately reflect the pronunciation of lenited stops in at least one language with

Table 4.2: Elicitation of stimuli from Spanish and English talkers for Experiments 2 and 3

Stimulus	**Orthography, Block**	
	Spanish Speakers	**English Speakers**
[aba]	aba, 2	aba, 1
[ada]	ada, 2	ada, 1
[aga]	aga, 2	aga, 1
[apa]	apa, 1	apa, 1/2
[ata]	ata, 1	ata, 1/2
[aka]	aka, 1	aka, 1/2
[aspa]		aspa, 1
[asta]		asta, 1
[aska]		aska, 1
[aβa]	aba, 1	aβa, 2
[aða]	ada, 1	aða, 1
[aɣa]	aga, 1	aɣa, 2

this pattern, whether they are approximants or true fricatives. English speakers were used because (unlenited) intervocalic voiced stops are phonotactically legal in English, but not in Spanish.

The native Spanish speakers were adult L2 speakers of English who were naïve to the purposes of the experiment. They recorded the stimuli in two blocks. The first block consisted of the stimulus items [aTa] and [aZa], which are phonotactically legal in Spanish, in standard Spanish orthography (see table 4.2). Stimuli were presented to the talkers in a randomized block, with each stimulus presented 20 times. Each token was printed on a separate square of paper; talkers worked through the stack of paper at their own pace, reading each token with initial stress.[1] The second block consisted of the [aDa] stimulus items, which are

[1]Initial stress was used rather than final stress so that the segments of interest would not occur in the onset of a stressed syllable, a canonically 'strong' position (Beckman 2004[1998]; Smith 2004, 1441) that is expected to resist lenition. Although the Spanish spirantization process is

phonotactically illegal in Spanish (Spanish has spirantization of voiced stops intervocalically, among other environments). For this block, talkers were instructed to pronounce the consonants as they would be pronounced in English (i.e., as stops); the talkers and the experimenter discussed how the English and Spanish pronunciations differ to ensure that the talkers understood what was being asked of them.

The native English speakers were linguistically trained American students in their 20s who were naïve to the purposes of the experiment. Again, the stimuli were recorded in two blocks. The first block consisted of the stimulus items [aTa], [aDa], and [aða], which are phonotactically legal in English (but not [aβa] or [aɣa], which are not). Subjects were requested to avoid flapping in [ata] and [ada]; since flapping is optional, these pronunciations were still phonotactically legal, although perhaps in a more formal register. Stimuli were presented in IPA (see table 4.2). The first block also contained the additional stimulus items [asTa], which were recorded in hopes of obtaining reduced aspiration on the voiceless stops. Stimuli were presented and recorded as described above. The second block consisted of the stimuli [aβa] and [aɣa], which contain segments absent from the English inventory; in addition, the [aTa] stimuli were presented again, and talkers were asked to avoid aspirating the voiceless stops.

Selection of Stimuli

Naturally produced stimuli were used because the purpose of this experiment is to determine how well listeners can distinguish between the relevant sounds, not to identify what cues they use to do so. However, there are three ways in

not sensitive to stress, other lenition processes are (such as English flapping).

which the production of these stimuli might bias the results of the experiment:

1. English voiced and voiceless stops contrast in aspiration, and not merely voicing. This property is especially pronounced at the beginning of stressed syllables, but seems to be present even intervocalically (see figure 4.1 below). Thus, the voiced and voiceless stops produced by the English talkers might be easier to discriminate than the voicing contrast in a language that does not use aspiration to the same extent.

2. In producing the [aβa] and [aɣa] stimuli, the English speakers tended to produce relatively long initial vowels (see figures 4.2 and 4.8), presumably because these stimuli were non-native and required extra attention. This property of those talkers' stimuli could be used by subjects as a cue to the Z $\sim$ D distinction that may not be found in natural speech, thus artificially increasing the salience of that distinction. This length difference could also interfere with subjects' perception of the T $\sim$ D distinction, where length of the preceding vowel is a common cue for voicing (see Kingston and Diehl (1994) and references therein).

3. As noted above, for all of the talkers, some of the stimuli involved non-native segments, phonotactics, or both. It is possible that the vowels in these non-native stimuli were distorted, thus providing an additional (artificial) cue to the relevant distinctions.

Of the 20 tokens of each stimulus produced by each talker, approximately 10 tokens were selected for use in the experiment. The number of tokens that were selected depended on the quality of the tokens and ranged between 6 and

13; in most cases (33 out of 45), the number was between 8 and 10. Tokens were analyzed in Praat (Boersma and Weenink 2007) and selected so as to maximize the naturalness of the tokens and minimize the potential confounds 1 and 3 discussed above, as follows:

1. English speakers' tokens of [aTa] were selected from the ordinary [aTa] stimuli in the first block. The [asTa] tokens were not used because of the effects of the coronal [s] on the formants of the first vowel. The unaspirated [aTa] tokens were not used because they were difficult for the English speakers to produce naturally.

2. All tokens with any obvious abnormality were excluded (e.g., tokens with stress on the final syllable, closure during a spirant, lack of closure during a stop, and so on).

3. All [aZa] tokens (of both English and Spanish speakers) were rated for naturalness by two native speakers of Spanish (not the same Spanish speakers who recorded stimuli). These speakers were asked to evaluate the tokens as Spanish nonsense words, paying attention only to the consonant. For each talker and place of articulation, the tokens with the highest ratings from both raters were selected.

4. For the English speakers, the tokens of the [aTa] stimuli were selected that had the shortest period of aspiration after the stop.

5. One of the Spanish speakers (talker 4 in the graphs below) produced tokens of the [aTa] stimuli with unusually long stop closures. For this talker, the [aTa] tokens with the shortest closures were chosen. [aTa] tokens for

the other Spanish speaker (talker 5) were selected like the [aDa] tokens, as described below.

6. After filtering by these criteria, the F1 and F2 values of the vowels of the remaining stimuli were measured. For each talker and place of articulation, the [aDa] tokens were chosen that were closest to the [aZa] and [aTa] tokens for that talker and place of articulation (as measured by the formants of the first vowel). The goal of this procedure was to ensure that the vowels of the [aDa] tokens were not systematically more similar to those of the [aZa] tokens than the [aTa] tokens, or vice versa. Thus, we can be reasonably sure that listeners' sensitivity to the relevant pairs is truly grounded in differences among the consonants, not accidental differences among the vowels.[2]

Selected tokens were trimmed, leaving 200 ms of silence on either side of the word, and amplitude-normalized using a Praat script that set the peak of each file at .8. The acoustic characteristics of the selected tokens, as relevant to the possible confounds described above, are given below with the results of the experiment.

Participants

24 native speakers of English participated in the experiment; all were students in undergraduate linguistics courses at the University of California, Santa Cruz. Subjects received either monetary compensation or extra credit, depending on the course. Subjects ranged in age from 18 to 23 years old and none were native speakers of a language other than English.

[2]Of course, some of the cues to the voicing and continuancy distinctions of interest are found in the vowels as well as the consonants. Since the formant values were measured at the midpoints of the vowels, it is reasonable to assume that they were affected by the adjacent consonants as little as possible.

Procedure

All instructions and stimuli were presented, and subjects' responses recorded, using SuperLab 4.0.5. The experiment involved a 'same'-'different' task: subjects were presented with a pair of tokens and asked to indicate whether they had heard two different words or two repetitions of the same word. The stimulus presentation was purely auditory and subjects responded via colored buttons on a button box (Cedrus Response Pad, model RB-620); thus, the stimuli were not represented to the subjects orthographically in any way during the experiment. This avoidance of written representations was intentional; in English, for example, [g] and [k] have standard orthographic representations that subjects would be familiar with, while [ɣ] does not. Subjects were told that the stimuli were "not words from any particular language"; they were also informed that the vowels were the same in all of the words and were instructed to pay attention only to the consonants.

All pairs of tokens that were presented were within-talker and within-place. Within each condition, there were three types of 'same' trials (Z $\sim$ Z, D $\sim$ D, and T $\sim$ T) and four types of 'different' trials (Z $\sim$ D, D $\sim$ Z, T $\sim$ D, and D $\sim$ T). Each token appeared in one 'same' trial and one 'different' trial (two 'different' trials in the case of the [aDa] tokens), with some repetitions when a given talker had more tokens for one of the stimuli paired in a 'different' trial than the other; however, each combination of tokens was presented only once. 'Same' trials were pairs of distinct tokens, never two repetitions of the same token. In total, there were approximately 70-80 trials for each pairing of talker and place of articulation, depending on how many tokens for that talker and place were available.

The first part of the experiment consisted of a practice session, during which subjects were trained on the relevant contrasts. After each trial, subjects were told whether they had responded correctly. The practice session ended after subjects had heard at least 10 trials at each place of articulation and after either they had answered 8 out of 10 trials in a row correctly, or after 5 minutes, whichever came first.

The main part of the experiment was presented in four blocks. The first block consisted of all trials. The second block consisted of only the labial trials, the third block of only the coronal trials, and the fourth block of only the dorsal trials. Subjects were given no feedback during these blocks. For each trial, both the response and the reaction time[3] were recorded. Subjects were given the opportunity to take a break before each block. The entire experiment lasted between 45 minutes and an hour.

4.1.2 Results

Acoustic Properties of the Stimuli

Figure 4.1 shows the duration of aspiration in the [aTa] stimuli. Unsurprisingly, the tokens produced by English talkers that were used in the experiment had significantly more aspiration (average 68 ms) than the tokens produced by Spanish talkers (average 23 ms; $p = 4.5 \times 10^{-49}$). In addition, the tokens produced by English talkers that were selected for use in the experiment had significantly less aspiration than all of the tokens that were actually produced by English talkers

[3] Reaction times were recorded from the onset of the second stimulus, then recalculated from the end of the second stimulus (including the 200 ms of silence). Responses that occurred before the end of the second stimulus are omitted; these trials account for less than .2% of all trials in the experiment. Measuring reaction times from the end of the consonant produces almost identical results, as discussed with the results below.

(average 76 ms; $p = 6.8 \times 10^{-5}$).

Figure 4.1: Density curves for aspiration duration in [aTa] stimuli for Experiments 2 and 3

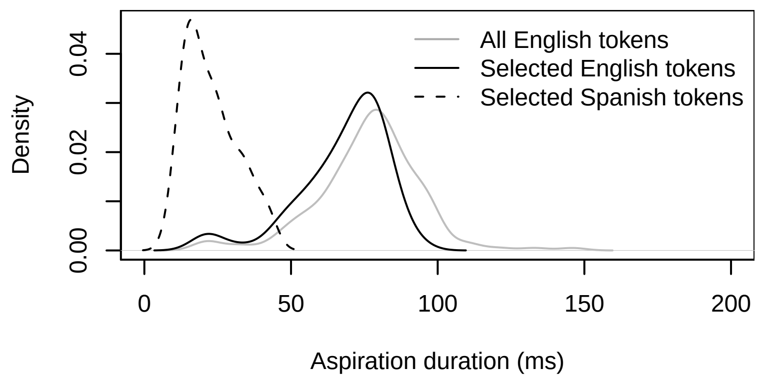


Figure 4.2: Length of first vowel in stimuli for Experiments 2 and 3. Stars mark within-language differences that are significant at $\alpha = .05$

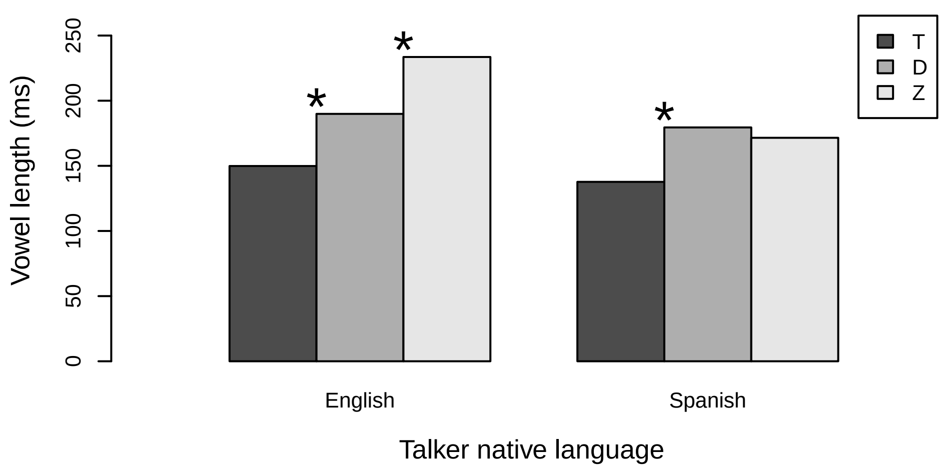
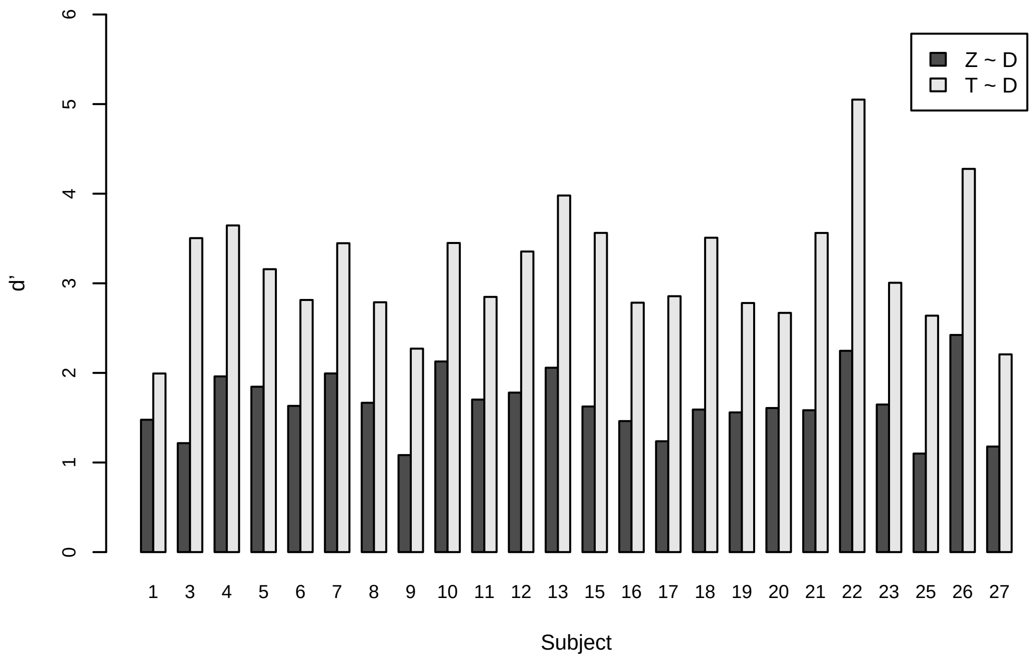


Figure 4.2 shows the duration of the first vowel in the stimuli used in the experiment. Vowel length is shown separately for English and Spanish talkers. As expected, for both groups of talkers, the vowel is significantly longer in [aDa]

Figure 4.3: Sensitivity to Z $\sim$ D vs. T $\sim$ D by subject in Experiment 2. All within-subject differences are significant at $\alpha = .05$. For each d', $600 \leq n \leq 633$



stimuli than in [aTa] stimuli ($p = 4.0 \times 10^{-8}$ for English talkers; $p = 4.6 \times 10^{-6}$ for Spanish talkers). The vowel is also longer in [aZa] stimuli than in [aTa] stimuli ($p = 5.8 \times 10^{-30}$ for English; $p = 1.0 \times 10^{-4}$ for Spanish). In addition, for English but not for Spanish talkers, the vowel is longer in the [aZa] stimuli than in the [aDa] stimuli ($p = 3.2 \times 10^{-9}$; the difference between [aZa] and [aDa] is not significant for Spanish talkers).

‘Same’-‘Different’ Responses

Figure 4.3 shows sensitivity to the Z $\sim$ D and T $\sim$ D differences, broken down by subject. Sensitivity is measured by d', calculated from subjects’ ‘same’-

'different' responses, using the Independent-Observation Model.[4] Each subject is significantly more sensitive to the voicing distinction than to the continuancy distinction; when the results for each subject are broken down by place, as shown in figure 4.4, the direction of the effect is the same in every case. Significance for d' was calculated using the G statistic of Gourevitch and Galanter (1967).

Figure 4.5 shows sensitivity by talker and place of articulation. For each combination of talker and place, sensitivity to T $\sim$ D is significantly greater than sensitivity to Z $\sim$ D. Recall that talkers 1 – 3 are the English speakers, and talkers 4 and 5 the Spanish speakers.

Subjects were slightly more sensitive to all differences in later blocks than in the first block; however, the differences in sensitivity are very small.

[4]The design of this experiment is neither a pure 'fixed' design nor a pure 'roving' one. See Kabak and Idsardi (2007, fn. 6) for an argument for the appropriateness of the Independent-Observation Model for this kind of experiment.

Figure 4.4: Sensitivity to Z $\sim$ D vs. T $\sim$ D by subject and place of articulation in Experiment 2. Stars mark within-subject and within-place differences that are significant at $\alpha = .05$. For each d', $194 \leq n \leq 213$. Within each plot, the three pairs of bars are for labials, coronals, and dorsals (left to right), and the y-axis measures d'

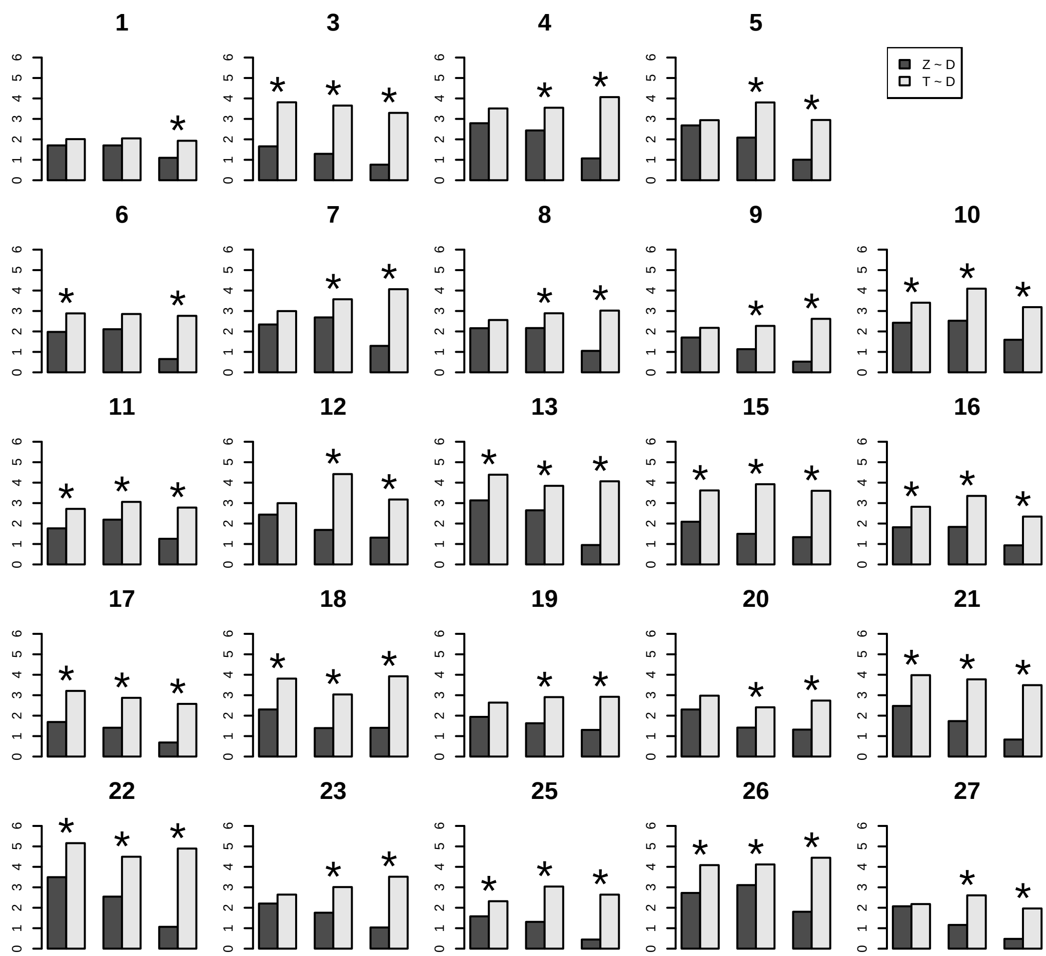
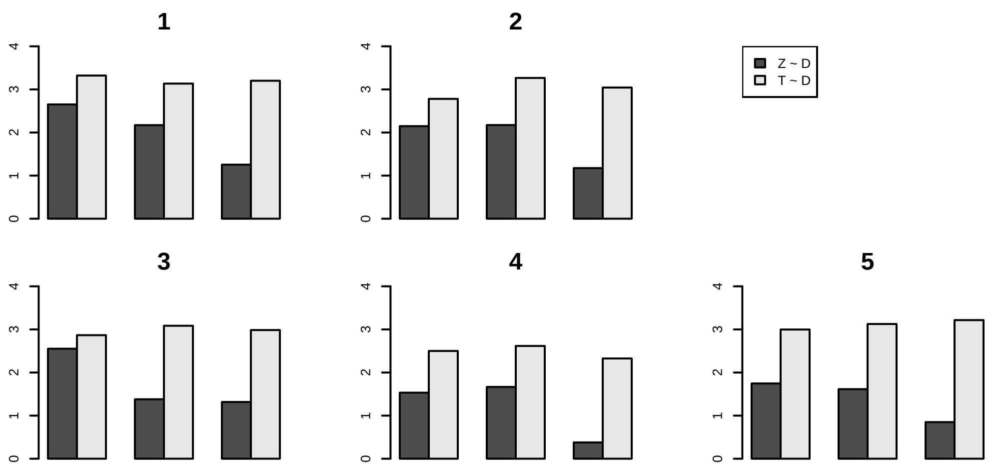


Figure 4.5: Sensitivity to Z $\sim$ D vs. T $\sim$ D by talker and place of articulation for Experiment 2. All within-talker and within-place differences are significant at $\alpha = .05$. For each d', $864 \leq n \leq 1203$. Within each plot, the three pairs of bars are for labials, coronals, and dorsals (left to right), and the y-axis measures d'



Reaction Times

Reaction times were analyzed with a linear mixed-effects model, which predicted log reaction time from the factors Comparison (Z $\sim$ D vs. T $\sim$ D), Place, Trial (the number of the trial for each subject), and their two-way interactions as fixed effects and the factors Talker and Subject as random effects. The model also included by-Subject random effects of Trial. Significance of each fixed effect was estimated from its t-statistic with degrees of freedom equal to the number of observations minus the number of fixed-effects parameters (Baayen 2008, 248). Only reaction times for 'different' trials to which subjects responded correctly were included. In general, responses were faster in the same conditions in which subjects exhibited greater sensitivity, as detailed below.

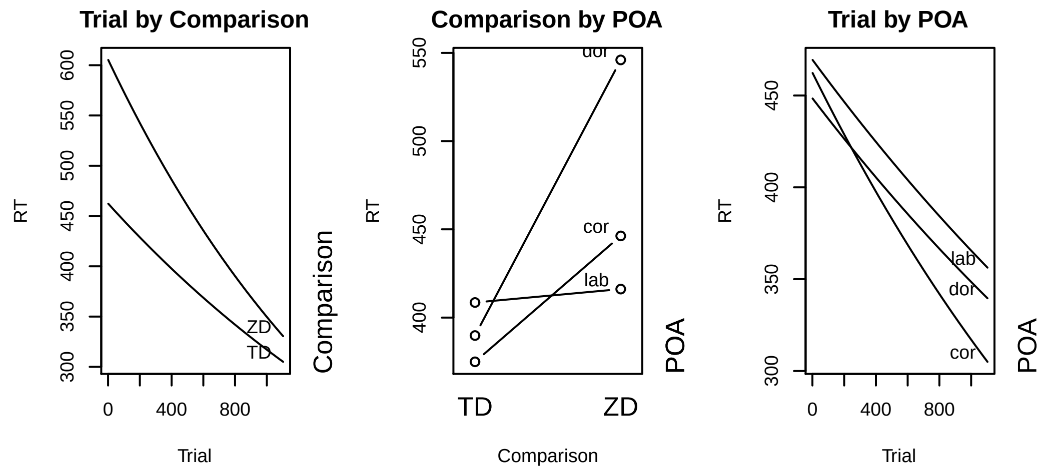
A model of this type with multiple categorical factors, such as Comparison and Place, does not produce information about the main effect of one factor independently of the other. For example, the main effect of Comparison in this model is actually the effect of Comparison within the level of Place that happens to be chosen as the baseline (that is, among either labials, coronals, or dorsals, but not across the three places). For the crucial effect of Comparison, I built three separate models, one with each place of articulation as the baseline, in order to determine whether the effect of Comparison was significant for each place. For other effects, I report the results from the model with coronals as the baseline; unless otherwise noted, all significant effects in this model were also significant in the two other models.

The effect of Comparison was significant for all three places of articulation: labials ($p = 1.6 \times 10^{-3}$), coronals ($p = 2.7 \times 10^{-12}$), and dorsals ($p = 1.2 \times 10^{-21}$). For all three places of articulation, subjects responded more slowly to Z $\sim$ D trials than they did to T $\sim$ D trials. The middle graph in figure 4.6 shows the partial effects of the interaction between Comparison and Place.

There was a significant effect of Trial ($p = 4.7 \times 10^{-7}$) such that subjects got faster over the course of the experiment. There was also a significant interaction between Comparison and Trial ($p = 3.1 \times 10^{-3}$); subjects improved more quickly on Z $\sim$ D trials than they did on T $\sim$ D trials. Finally, there was a marginal interaction between Place and Trial: subjects improved more quickly for coronals than they did for either labials ($p = .088$) or dorsals ($p = .034$); the difference between labials and dorsals was not significant ($p = .97$). Figure 4.6 shows the partial effects of the interactions between Trial and Comparison (left) and between Trial and Place (right).

To determine how robust the effect of Comparison is, this model was compared

Figure 4.6: Partial effects of the interactions between Trial and Comparison, Comparison and Place, and Trial and Place in Experiment 2



to one that included an interaction between Subject and Comparison as a random effect, and one that included an interaction between Talker and Comparison as a random effect. Either interaction, if significant, would suggest that the effect of Comparison seen above is particular to this group of subjects or talkers. The likelihood ratio test described in Baayen (2008, 253) showed that the improvement in the model that added an interaction between Subject and Comparison approached significance ($p = .061$), while the model that added an interaction between Talker and Comparison was significantly improved ($p = 1.7 \times 10^{-3}$). However, none of the by-subject or by-talker interactions reversed the direction of the effect: reaction times were slower for Z $\sim$ D comparisons for each individual subject and talker. Thus, difficulty with Z $\sim$ D trials is robust across subjects and talkers.

Finally, recall that reaction times were measured from the end of the stimulus. An alternative method would be to measure reaction time from the end of the consonant, since it is the consonants (not the vowels) that consitute the comparisons of interest. The choice between these options depends on two factors:

1. Does the length of the second vowel vary systematically by consonant (or talker)?

2. Did subjects use cues from the second vowel in the perceptual task?

If the length of the second vowel varies systematically among the different stimuli, then measuring reaction times from a point after the end of the vowel may artificially increase or decrease reaction times for certain stimuli. On the other hand, if subjects used cues from the second vowel in the discrimination task, then measuring from the end of the vowel may be a more accurate representation of the point at which subjects had enough information to make a decision.

The answer to question 1 is 'yes'. For example, for every talker except talker 4, the second vowel in the [aZa] stimuli is significantly longer than the second vowel in the [aDa] stimuli. What is not certain, however, is whether subjects used this difference in duration – or other cues within the second vowel – to distinguish the two types of stimuli. In the absence of a clear answer, I built a second set of models based on the reaction times as measured from the end of the consonant. The resulting models are nearly identical to those based on reaction times measured from the end of the stimulus. All of the effects reported above as significant are also significant in this second set of models, except for the result of adding by-subject and by-talker interactions with Comparison. The latter models are not significantly improved by adding such an interaction, either for subjects ($p = .38$) or for talkers ($p = .39$).

4.1.3 Discussion

Overall Results

Overall, the results of the experiment are consistent with a perceptual account of the broad strokes of lenition: listeners are less sensitive to the distinction between voiced stops and spirants intervocalically than they are to the distinction between voiced and voiceless stops. This difference was manifested both in subjects' 'same'-'different' responses (reflected in the d' scores) and in their reaction times: subjects were quicker to identify the more salient voicing distinction than the continuancy distinction.

This effect is highly robust and seems unlikely to be due to the particulars of the experimental design. The difference in d' scores was seen for every combination of talker and place of articulation; this fact indicates that the sensitivity difference is probably not a peculiarity of a few talkers' pronunciations. Nor is the effect likely to depend on particular characteristics of the experimental subjects: the difference in d' scores was seen for every combination of subject and place of articulation, and even with a random effect for the interaction of Subject and Comparison, every subject responded more slowly on Z $\sim$ D trials than on T $\sim$ D trials.

Effect of Acoustic Characteristics of Stimuli

Recall that there are at least two ways in which the English talkers' tokens might have influenced the main result that the voicing distinction is more salient than the continuancy distinction: the use of aspiration to cue voiceless stops, and the difference in length between the initial vowels in the [aDa] and [aZa] stimuli. The aspiration in the [aTa] stimuli might have artificially enhanced the T ~ D distinction, while the long vowels in the [aZa] stimuli might have artificially enhanced the Z ~ D distinction.

It is unlikely that the English talkers' aspiration is driving the entire difference in perceptibility between the Z ~ D and T ~ D comparisons. The overall effect holds not only for the English talkers, who produced a significant amount of aspiration, but also for the Spanish talkers, who produced far less. Indeed, if anything, we might expect the subjects' sensitivity to the T ~ D contrast for the Spanish talkers to be artificially *low* – as English speakers, the subjects would expect to be able to rely on the aspiration cue that was much less pronounced in the Spanish tokens.

As for vowel length, the effect of the long vowels in the [aZa] tokens should, if anything, encourage the opposite of the effect found here: by using vowel length as a cue to the Z ~ D distinction, subjects should have been better able to distinguish those stimuli than they otherwise would have been able to. The T ~ D distinction was nevertheless more salient, suggesting that this is a robust result.

Effect of the English Consonant Inventory

Finally, it is important to consider whether the main result that the T ~ D distinction is more salient than the Z ~ D distinction is simply an artifact of the consonant inventory of the English-speaking subjects. For example, since English has phonemic [k] and [g] but lacks [ɣ], it is only to be expected that English speakers are better able to tell the difference between phonemic sounds in their language ([g] and [k]) than between a phonemic and non-phonemic sound ([g] and [ɣ]) (Boomershine et al. 2008), especially if the unfamiliar [ɣ] was assimilated to the native category [g] (Best et al. 1988; Kuhl and Iverson 1992). A similar explanation could be put forward for the labials: English has [p] and [b], but not [β].[5]

However, it is unlikely that the English segment inventory alone is responsible for the main result that the voicing distinction is more salient than the continuancy distinction. The result holds for coronals as well: even though all three consonants tested in the coronal conditions are phonemic in English ([ð], [d], and [t]), English speakers were less sensitive to one distinction than the other. Indeed, the interaction between Comparison and Place illustrated in figure 4.6 suggests that coronals suffered *more* in the Z $\sim$ D condition than the labials did, despite their phonemic advantage.

In addition, there is reason to believe that the results for labials and dorsals are just as relevant to understanding spirantization as those for coronals. As discussed in chapter 2, the typological survey of Gurevich (2004) shows that spirantization of voiced stops, like other lenition processes, is usually non-neutralizing. In other words, if a language spirantizes a voiced stop, the resulting voiced spirant exists in the language only as an allophone of the stop; the two are not phonemically contrastive, just as English [g] and [ɣ] do not contrast. On the other hand, many of these languages *do* have voiceless stops that contrast with the voiced stops, just as English [k] and [g] constrast.

There are at least two possible explanations for this state of affairs. One is that once intervocalic spirantization becomes part of a language's phonology,

[5] It is possible that subjects assimilated these [β]s to the native categories [v] or [w]. To the extent that subjects were successful in assimilating [β] to a native segment other than [b] (an "opposing-category assimilation" in the terminology of Best et al. (1988, 347)), the same argument applies here that is discussed below for coronals.

that language is likely to lose the contrast between stops and spirants in other environments as well. Another possibility, however, is that spirantization is more likely to enter a language in the first place if that language does not have a contrast between voiced stops and spirants. If the latter is true, then the (non-)phonemic status of [k] ∼ [g] ∼ [ɣ] for English speakers is reflective of the situation for languages that actually acquire lenition; in that case, the results for dorsals and labials may represent the very conditions that encourage spirantization in the first place.

Effect of Place of Articulation

The results of Experiment 2 clearly show that the voicing distinction is perceptually more salient than the continuancy distinction for the relevant segments and environments. Interestingly, the interaction between Comparison and Place illustrated in figure 4.6 suggests that this difference in perceptual salience is not equally large at every place of articulation. Experiment 2 tests whether there are indeed differences by place, or whether this result was simply an artifact of the English-speaking subjects' native consonant inventories.

4.2 Experiment 3: Effect of Place of Articulation

As noted above, Spanish is one language that has a variant of the lenition process of interest: the voiced stops [b], [d], and [g] become the spirants [β], [ð], and [ɣ] between vowels (among other environments, depending on the dialect). In addition, Spanish contains all three voiceless stops investigated here ([p], [t], and [k]), which contrast phonemically with the voiced stops/spirants. Thus, native Spanish speakers cannot provide data on whether the T $\sim$ D or Z $\sim$ D distinction is more salient: since allophonic distinctions are perceived more poorly than phonemic ones (Boomershine et al. 2008), we expect Spanish-speaking subjects to be more sensitive to the T $\sim$ D distinction purely by reason of their native consonant inventory.

However, the effect of the native segment inventory of Spanish should be the same at each place of articulation: for each place, the T $\sim$ D distinction is phonemic and the Z $\sim$ D distinction is allophonic. Therefore, unlike English speakers, Spanish speakers provide the perfect opportunity to study those perceptual differences by place that are inventory-independent.

4.2.1 Design

11 native speakers of Spanish participated in the experiment; all were undergraduate students at the University of California, Santa Cruz. Subjects received either monetary compensation or extra credit, depending on which courses they were recruited from. The procedure was exactly the same as that in Experiment 2, except that all of the instructions were in Spanish. The Spanish instructions were intended to encourage the subjects to draw on their Spanish resources when perceiving the stimuli, especially for those subjects who were native bilingual speakers of both Spanish and English (subjects 2, 3, 6, 7, and 11). Excluding these subjects from the analyses below does not substantially affect the results. In the discussion of reaction times below, I report the results for an analysis of

all 11 subjects; unless otherwise noted, all significant effects are also significant in an analysis of only the subjects who are not also native speakers of English. No subject was a native speaker of any language besides Spanish or English, and no subject had participated in the previous experiment.

4.2.2 Results

Acoustic Properties of the Stimuli

Figure 4.7: Duration of aspiration by place of articulation in [aTa] stimuli for Experiments 2 and 3. All pairwise within-language differences are significant at $\alpha = .05$

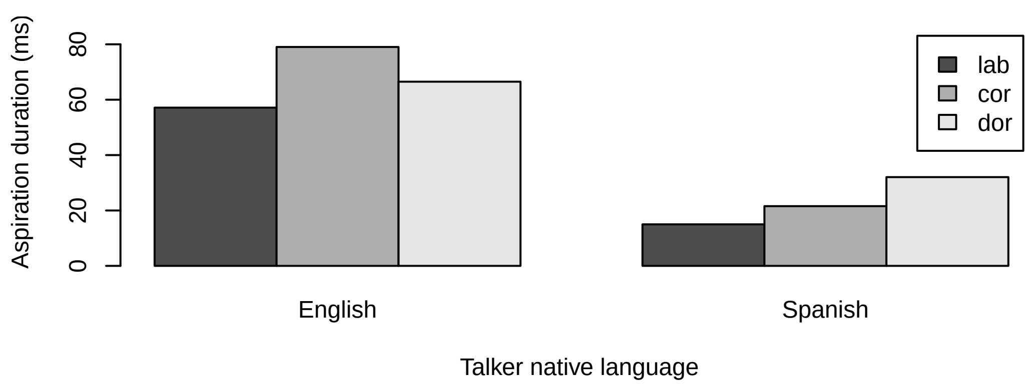
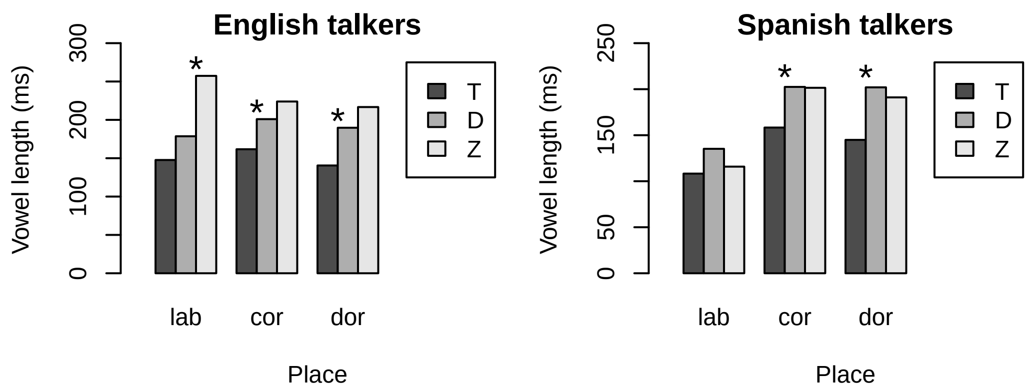


Figure 4.7 shows the duration of aspiration in the [aTa] stimuli, broken down by place and talker's native language. For both groups of talkers, the [apa] tokens had the shortest aspiration. Among the English speakers, the [ata] tokens had the longest aspiration, while among the Spanish speakers, the [aka] tokens had the longest.

Figure 4.8 shows the duration of the first vowel, broken down by place and talker's native language. The patterns shown in figure 4.2, where length was

Figure 4.8: Length of first vowel by place of articulation in stimuli for Experiments 2 and 3. Stars mark within-language and within-place differences that are significant at $\alpha = .05$



pooled across place, are largely preserved here, with some loss of significance. For both groups of talkers, the difference in vowel length between [aTa] and [aDa] stimuli is significant only for coronals and dorsals. Among English speakers, the unusually long vowel durations in the [aZa] stimuli are significant only for tokens of [aβa].

'Same'-'Different' Responses

Figure 4.9 shows subjects' sensitivity to the Z $\sim$ D and T $\sim$ D differences by place of articulation, pooled across subjects. The difference is largest for dorsals, and comparable for labials and coronals. This pattern appears to hold for most (but not all) of the individual subjects, as shown in figure 4.10. Note that having an extremely large difference for dorsals does *not* seem to be correlated with whether the subject is also a native speaker of English: subjects 6, 7, and 11 all have especially large differences among the dorsals, but subjects 2 and 3 do not.

Figure 4.11 shows sensitivity by place of articulation and talker. The trend

Figure 4.9: Sensitivity to Z $\sim$ D vs. T $\sim$ D by place of articulation in Experiment 3. All within-place differences are significant at $\alpha = .05$. For each d', $5355 \leq n \leq 5727$

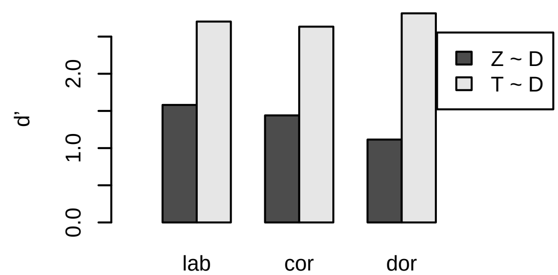
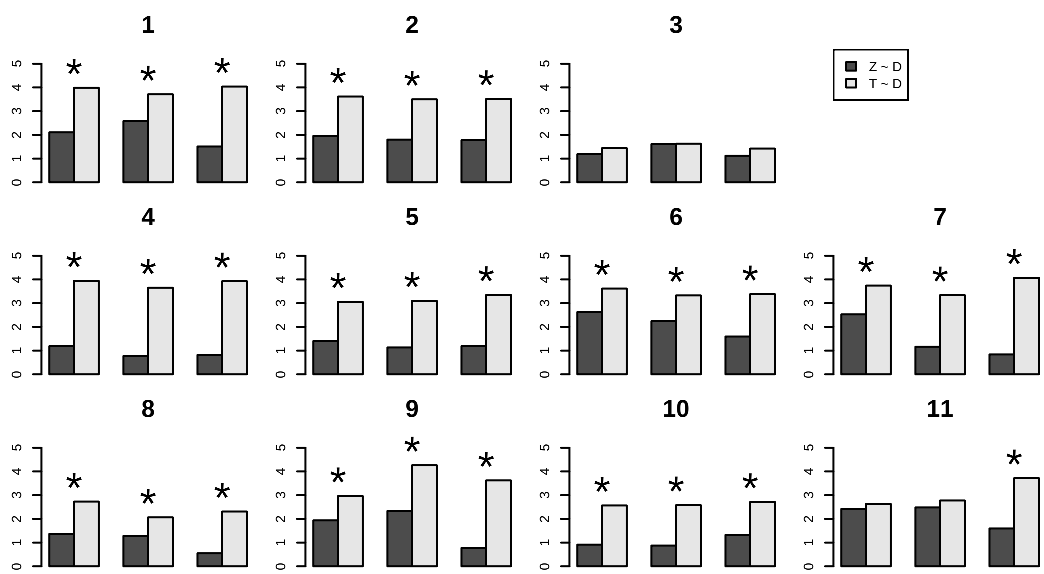
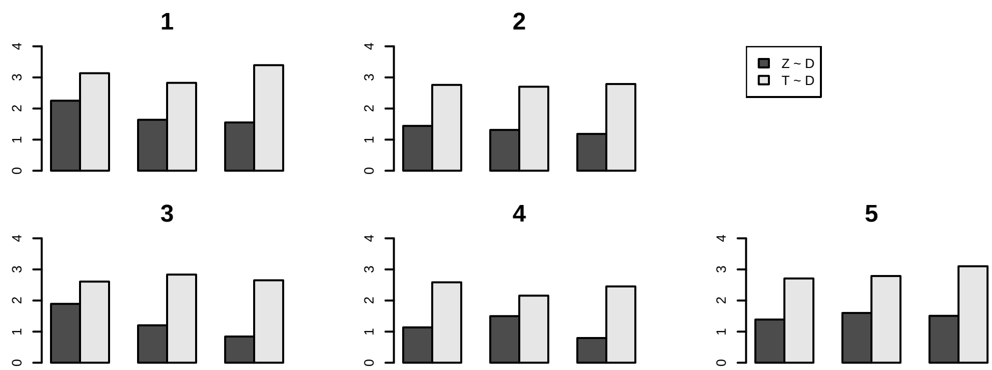


Figure 4.10: Sensitivity to Z $\sim$ D vs. T $\sim$ D by subject and place of articulation in Experiment 3. Stars mark within-subject and within-place differences that are significant at $\alpha = .05$. For each d', $198 \leq n \leq 216$. Within each plot, the three pairs of bars are for labials, coronals, and dorsals (left to right), and the y-axis measures d'



towards larger differences among dorsals is especially pronounced for talkers 1, 3, and 4.

Figure 4.11: Sensitivity to Z $\sim$ D vs. T $\sim$ D by talker and place of articulation for Experiment 3. All within-talker and within-place differences are significant at $\alpha = .05$. Within each plot, the three pairs of bars are for labials, coronals, and dorsals (left to right), and the y-axis measures d'



Reaction Times

Reaction time data was analyzed in exactly the same way as described for Experiment 2. Adding interactions between Comparison and Subject and between Comparison and Talker resulted in significant improvements to the model of reaction times for Experiment 3; therefore, those interactions were included in the final model. (For the subset of subjects who are not native speakers of English, only the addition of an interaction between Comparison and Subject was a significant improvement.)

For T $\sim$ D trials, subjects responded more quickly to coronals than to either labials ($p = 7.7 \times 10^{-4}$) or dorsals ($p = 4.7 \times 10^{-3}$); the difference between labials and dorsals was not significant ($p = .24$).[6] For Z $\sim$ D trials, subjects responded more slowly to dorsals than to either coronals ($p = 2.8 \times 10^{-8}$) or

[6] For the subset of subjects who are not native speakers of English, the difference between coronals and dorsals was not significant ($p = .13$), but the difference between labials and dorsals was ($p = 5.7 \times 10^{-3}$): subjects responded more quickly to dorsals than to labials.

labials ($p = 1.7 \times 10^{-6}$); the difference between labials and coronals was not significant ($p = .32$).[7] From these results, we can draw three conclusions about the size of the effect of Comparison at different places of articulation:

- The difference between the Z $\sim$ D and T $\sim$ D comparisons is greater among coronals than among labials: subjects responded more quickly to coronals than to labials on T $\sim$ D trials, but for Z $\sim$ D trials, the two places were approximately the same.

- The difference between the two comparisons is greater among dorsals than among labials: although subjects responded at about the same rate to both places on T $\sim$ D trials, subjects responded more slowly to dorsals than to labials on Z $\sim$ D trials. For the subset of non-English-speakers, we can draw the same conclusion in a slightly different way: as with the difference between coronals and labials, subjects responded more quickly to dorsals than to labials on T $\sim$ D trials; for Z $\sim$ D trials, however, the advantage of dorsals disappeared, and subjects responded to the two places at about the same rate.

- Possibly, the difference between the two comparisons is greater among dorsals than among coronals: for the subset of non-English-speakers only, responses were about the same in the T $\sim$ D trials for coronals and dorsals; for the Z $\sim$ D trials, on the other hand, responses were slower for dorsals.

Analyses of reaction times from the end of the consonant produce exactly the same pattern of significant and non-significant effects, except that responses were

[7] For the subset of non-English-speakers, the difference between dorsals and labials was not significant ($p = .18$).

significantly faster to coronals than to labials in Z $\sim$ D trials ($p = .021$).

4.2.3 Discussion

Effect of Place of Articulation

The Spanish-speaking subjects, like the English-speaking subjects, were more sensitive to (and responded faster to) the voicing distinction than the continuancy distinction. This result was expected on the basis of the Spanish consonant inventory alone: the voicing distinction, but not the continuancy distinction, is phonemic for Spanish speakers for these segments.

The new result of Experiment 3 is that the effect of comparison type depends on place of articulation. The differences in sensitivity by place, and the interactions between place and comparison type in the reaction times, suggest that the size of the effect is greatest for dorsals and smallest for labials. Thus, the continuancy distinction may be difficult to perceive in general, but it is *especially* difficult for dorsals. This effect is *not* predicted on the basis of the Spanish consonant inventory; thus, the results of Experiment 3 provide information about the perceptibility of these different places of articulation independent of segment inventory.

Effect of Acoustic Properties of the Stimuli

To be confident that the distinction between [aɣa] and [aga] is especially poorly perceived, we must ask whether the differences that were observed for each place of articulation could be the result of particular acoustic properties of these stimuli. Recall that two cues might be influencing the relative perceptibility of the T $\sim$ D and Z ∼ D distinctions: aspiration in [aTa] tokens and length of the first vowel.

As discussed above, the Spanish speakers produced more aspiration in the [aka] tokens than at any other place of articulation. If subjects picked up on this cue, then their discrimination of [aka] and [aga] may have been artificially inflated; in turn, it is possible that the difference between the [aɣa] ∼ [aga] and [aka] ∼ [aga] distinctions is no greater than it is at other places of articulation (although both dorsal distinctions are lower than the corresponding labial or coronal distinctions). However, an explanation along these lines cannot account for the fact that the subjects in Experiment 3 were just as sensitive overall to the [aka] ∼ [aga] distinction for the English-speaking talkers ($d' = 2.88$) as for the Spanish-speaking talkers ($d' = 2.73$; the difference is not significant, $p = .36$).

As for vowel length, figure 4.8 and the associated discussion show that there are two primary ways in which the overall effects of consonant type on vowel length are modulated by place: English speakers' long vowels in [aZa] stimuli are significantly different from those in [aDa] stimuli only for labials, and neither group of speakers exhibits a significant difference in vowel length between tokens of [apa] and [aba]. Either of these effects might have reduced the difference between the [aβa] ∼ [aba] and [apa] ∼ [aba] comparisons: the first by increasing the perceptibility of the [aβa] ∼ [aba] distinction by providing an extra cue for [aβa] stimuli, and the second by decreasing the perceptibility of the [apa] ∼ [aba] distinction by eliminating a cue to stop voicing.

First, to assess the effect of the English-speaking talkers' long vowels in the [aβa] tokens, we can examine subjects' sensitivity to just the Spanish-speaking talkers, for whom the difference in vowel length between [aβa] and [aba] is not significant (and, indeed, the [aβa] tokens have *shorter* vowels than the [aba] tokens). Unsurprisingly, subjects were more sensitive to the [aβa] $\sim$ [aba] distinction for the English talkers ($d' = 1.82$) than for the Spanish talkers ($d' = 1.28$; the difference is significant, $p = 1.1 \times 10^{-5}$). However, even for tokens produced by the Spanish talkers, the effect of comparison type is greater for dorsals than it is for labials: a mixed-effects model of reaction times identical to the one described above but including only Spanish talkers reveals a significant interaction between Comparison and Place such that subjects responded faster to [aka] $\sim$ [aga] trials than to [apa] $\sim$ [aba] trials, but faster to [aβa] $\sim$ [apa] trials than to [aɣa] $\sim$ [aga] trials.

The impact of the lack of a significant difference in vowel duration between [apa] and [aba] tokens is more difficult to assess, since both groups of talkers have this property. A closer examination of the individual talkers, however, reveals that three of the five talkers do in fact exhibit a significant difference: talkers 2 ($p = 6.4 \times 10^{-3}$), 3 ($p = 3.2 \times 10^{-2}$), and 5 ($p = 2.2 \times 10^{-5}$). But subjects were no more sensitive to the [apa] $\sim$ [aba] distinction for these three talkers (joint $d' = 2.68$) than for the two remaining talkers who do not exhibit a difference in vowel length (joint $d' = 2.81$; the difference is not significant, $p = .41$). In addition, the only pair of individual talkers who had significantly different d's for the [apa] $\sim$ [aba] distinction was talkers 1 and 3: for talker 1, who does not have a significant difference in vowel length, subjects were *more* sensitive ($d' = 3.13$) than for talker 3, who does ($d' = 2.61$; $p = 3.8 \times 10^{-2}$). Thus, it seems unlikely that subjects suffered from insufficient cues to the voicing distinction in the labial stimuli for some talkers.

4.3 Experiment 4: Relative Perceptibility of Voicing and Spirantization for Voiceless Stops

Experiment 4 was designed to test the relative perceptibility of two logically possible (and attested) repairs for intervocalic voiceless stops: voicing and spirantization. The structure of the experiment is the same as that of Experiment 2, except that different stimuli were used.

4.3.1 Design

Recording of Stimuli

The stimuli for Experiment 4 included the 9 consonants given in table 4.3; as in Experiments 2 and 3, the stimuli had the form [a__a], with initial stress and with some consonant from table 4.3 intervocalically.

Table 4.3: Perceptibility comparisons in Experiment 4

	[−voi] Spirants		[−voi] Stops		[+voi] Stops
Labials	f	∼	p	∼	b
Coronals	θ	∼	t	∼	d
Dorsals	x	∼	k	∼	g
Cover Symbol	**S**	∼	**T**	∼	**D**

Three talkers were recorded for Experiment 4. Talker 1 was a male native speaker of Bulgarian and second-language speaker of English; talker 2 was a female native speaker of German and second-language speaker of English; talker 3 was a male native speaker of English and second-language speaker of German. Thus, for talkers 1 and 2, [x] was a native phoneme and [θ] a non-native phoneme with which

Table 4.4: Elicitation of stimuli for Experiment 4

Stimulus	**Orthography**
[aba]	aba
[ada]	ada
[aga]	aga
[apa]	apa
[ata]	ata
[aka]	aka
[afa]	afa
[aθa]	aθa
[axa]	axa

they had some familiarity (as second-language speakers of English); for talker 3, [θ] was a native phoneme and [x] was non-native (but familiar from German). Talker 1 also had linguistic training. All three talkers were naïve to the purposes of the experiment. Stimuli were presented to the talkers in a single block in IPA (see table 4.4); before recording, the talkers and experimenter discussed the intended pronunciation of each type of stimulus.

Selection of Stimuli

As was the case for Experiments 2 and 3, it is possible that the different native segment inventories of the talkers who produced the stimuli for Experiment 4 introduce bias that might influence the perceptual results. At least three possibilities come to mind:

1. As in Experiments 2 and 3, the English- (and German-)speaking talkers make use of a cue to the voicing distinction among stops that the Bulgarian-speaking talker lacks: aspiration. Thus, the D $\sim$ T distinction might be

easier to discriminate for the English- and German-speaking talkers.

2. All of the consonants that were non-native for at least some talkers were spirants ([θ] and [x]). It is possible that the center of gravity or the intensity of the frication noise in these segments differed by talker in ways that might influence the perceptibility of the S $\sim$ T distinction.

3. As in Experiments 2 and 3, the vowels in the non-native stimuli may have been distorted, thus introducing artificial cues to the relevant distinctions.

For each talker, 10 tokens of each stimulus were selected (except for talker 3's productions of [aθa], where only 8 tokens were viable). Tokens were selected as follows:

1. All tokens with any obvious abnormality were excluded.

2. For the English and German speakers, the tokens of the [aTa] stimuli were selected that had the shortest period of aspiration after the stop.

3. The F1 and F2 values of the remaining vowels were measured. For each talker and place of articulation, the [aDa] and [aSa] tokens were chosen that were closest to the [aTa] tokens for that speaker and place of articulation (as measured by the formants of the first vowel), such that the first vowel for the [aTa] tokens was not systematically closer to either those of the [aDa] tokens or those of the [aSa] tokens.

Tokens were trimmed and amplitude-normalized as in Experiments 2 and 3. Further acoustic characteristics of the stimuli are discussed below.

Participants

18 native speakers of English participated in the experiment; all were students in undergraduate linguistics courses at the University of California, Santa Cruz. Subjects received either monetary compensation or extra credit, depending on the course. Six subjects were native speakers of a second language besides English: subjects 2, 9, and 11 were native speakers of Spanish; subject 5 of Japanese; subject 15 of Mandarin; and subject 17 of Cantonese. Separate analyses were performed excluding these bilingual subjects; where the results for the subset of monolingual subjects differs from the group as a whole, this is noted below.

Procedure

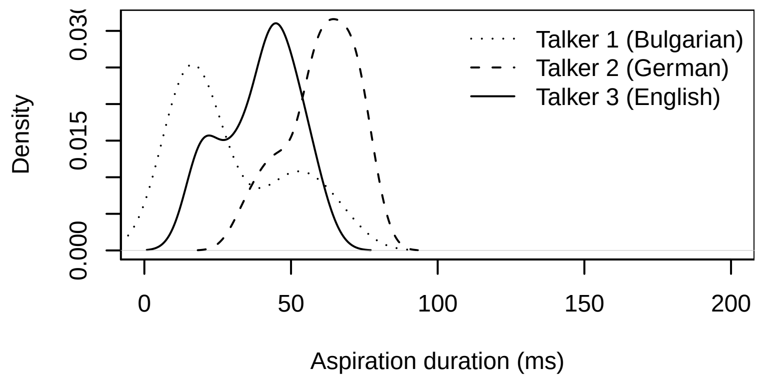
The experiment was run with E-Prime version 2.0 and a PST serial response box. The instructions and procedure were the same as in Experiment 2. There were three types of 'same' trials (D $\sim$ D, T $\sim$ T, and S $\sim$ S) and four types of 'different' trials (D $\sim$ T, T $\sim$ D, S $\sim$ T, and T $\sim$ S). The practice session in Experiment 4 lasted 3 minutes for all subjects, rather than terminating after criterion had been reached as in Experiments 2 and 3. The entire experiment lasted about 45 minutes.

4.3.2 Results

Acoustic Properties of the Stimuli

Unsurprisingly, as was the case for Experiments 2 and 3, there was a certain amount of inter-talker variation in the stimuli used in Experiment 4. The following discussion documents some differences among talkers that may have affected

Figure 4.12: Density curves for aspiration duration in [aTa] stimuli for Experiment 4



subjects' performance on the perceptual task.

Figure 4.12 shows the duration of aspiration in the [aTa] stimuli. The tokens produced by the German speaker had significantly more aspiration than those produced by the English speaker ($p = 1.4 \times 10^{-6}$); the tokens produced by the English speaker, in turn, had significantly more aspiration than those produced by the Bulgarian speaker($p = .013$).

Figure 4.13 shows the duration of the voiceless fricative by talker and place of articulation. Interestingly, after Holm correction for multiple comparisons, only one within-place difference turns out to be significant: talker 1 (Bulgarian) produced significantly longer [θ]s than talker 2 (German, $p = .016$). The difference between talkers 1 and 3 for [afa] approached significance ($p = .076$).

Figure 4.14 shows the center of gravity of the voiceless fricative by talker and place of articulation. For [θ], the native English speaker (talker 3) had a lower center of gravity than talkers 1 and 2 ($p = 2.7 \times 10^{-16}$ and 1.3×10^{-9}, respectively). For [x], the native speaker of Bulgarian (talker 1) had a higher center of gravity

Figure 4.13: Duration of consonant in [aSa] stimuli for Experiment 4. Stars mark within-place differences that are significant at $\alpha = .05$

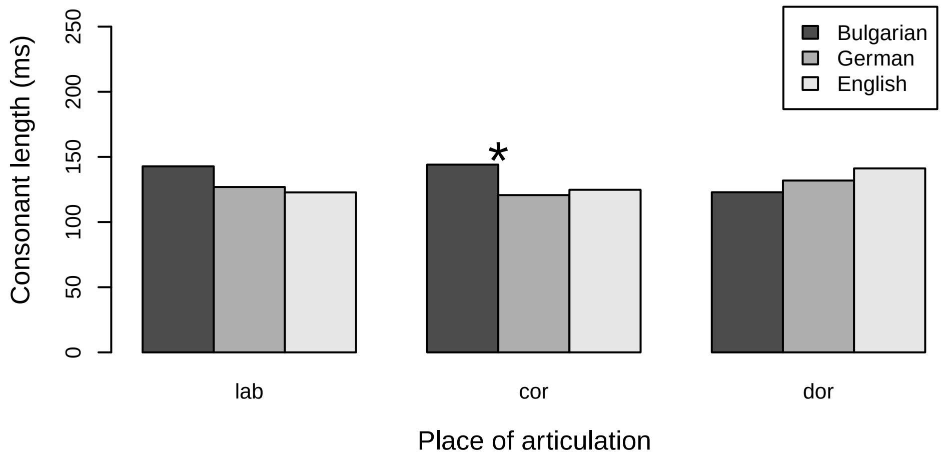
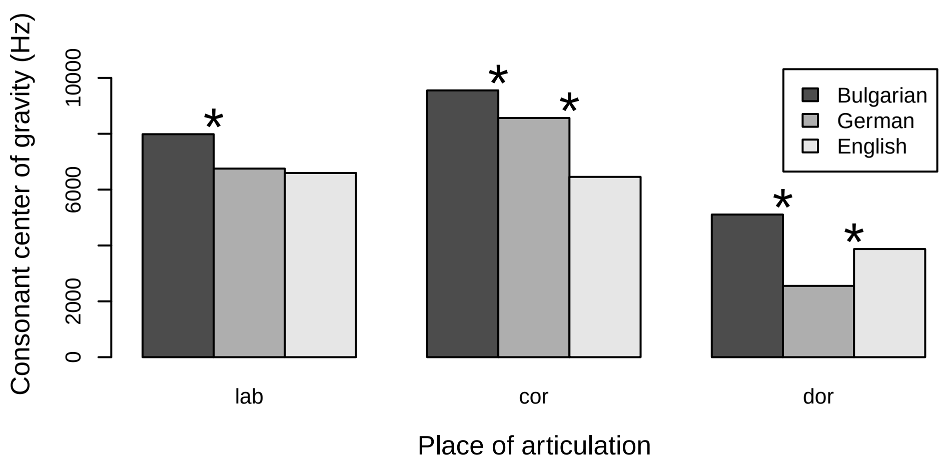
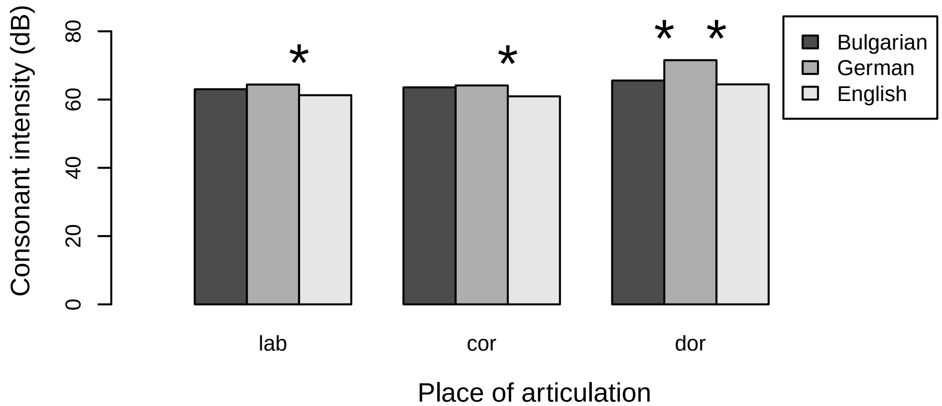


Figure 4.14: Center of gravity of consonant in [aSa] stimuli for Experiment 4. Stars mark within-place differences that are significant at $\alpha = .05$



than the native speaker of German (talker 2, $p = 3.7 \times 10^{-13}$); the center of gravity for talker 3's [x]s was between the two and significantly different from both ($p = 1.5 \times 10^{-4}$ and 6.1×10^{-5}, respectively). There are also differences for

Figure 4.15: Intensity of consonant in [aSa] stimuli for Experiment 4. Stars mark within-place differences that are significant at $\alpha = .05$

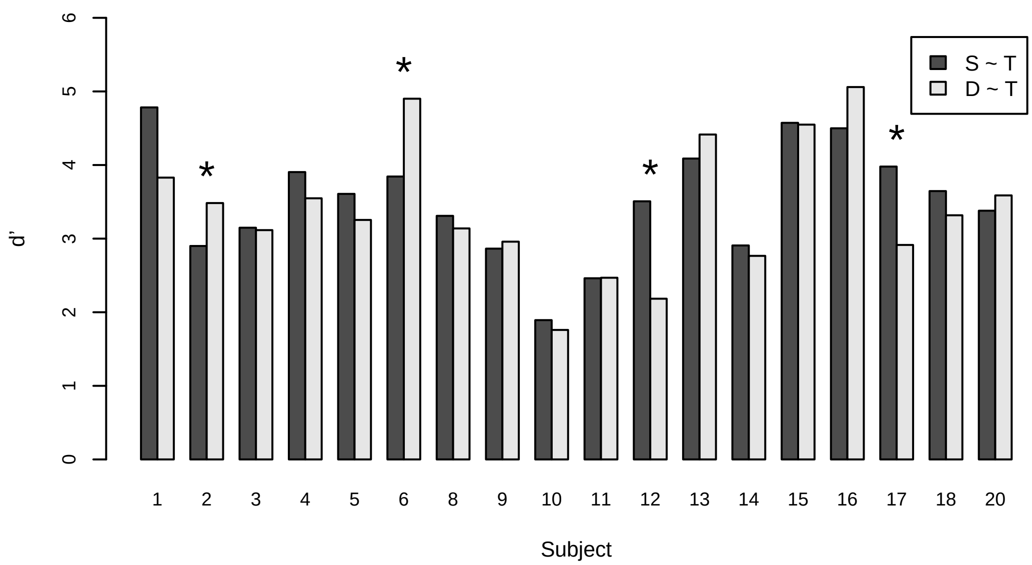


[f]: talker 1 produced tokens with a higher center of gravity than talkers 2 and 3 ($p = 1.5 \times 10^{-4}$ and 2.5×10^{-5}, respectively).

Figure 4.15 shows the intensity of the voiceless fricative by talker and place of articulation. The [θ]s produced by the native English speaker (talker 3) were significantly less intense than those of the native German speaker (talker 2, $p = 6.9 \times 10^{-3}$); the difference between talkers 3 and 1 for [θ] approached significance ($p = .051$). For [x], the native German speaker (talker 2) produced more intense tokens than talkers 1 and 3 ($p = 7.1 \times 10^{-9}$ and 1.5×10^{-11}). In addition, the native German speaker (talker 2) produced significantly more intense [f]s than the native English speaker (talker 3, $p = 6.4 \times 10^{-3}$).

While any of these by-talker differences has the potential to affect subjects' performance on the perceptual task, it is also possible that some or all of the differences could be factored out by subjects in the way that listeners ordinarily adjust to individual differences among talkers, such as differences in F_0. At any

Figure 4.16: Sensitivity to S $\sim$ T vs. D $\sim$ T by subject in Experiment 4. Stars mark within-subject differences that are significant at $\alpha = .05$. For each d', $n = 540$

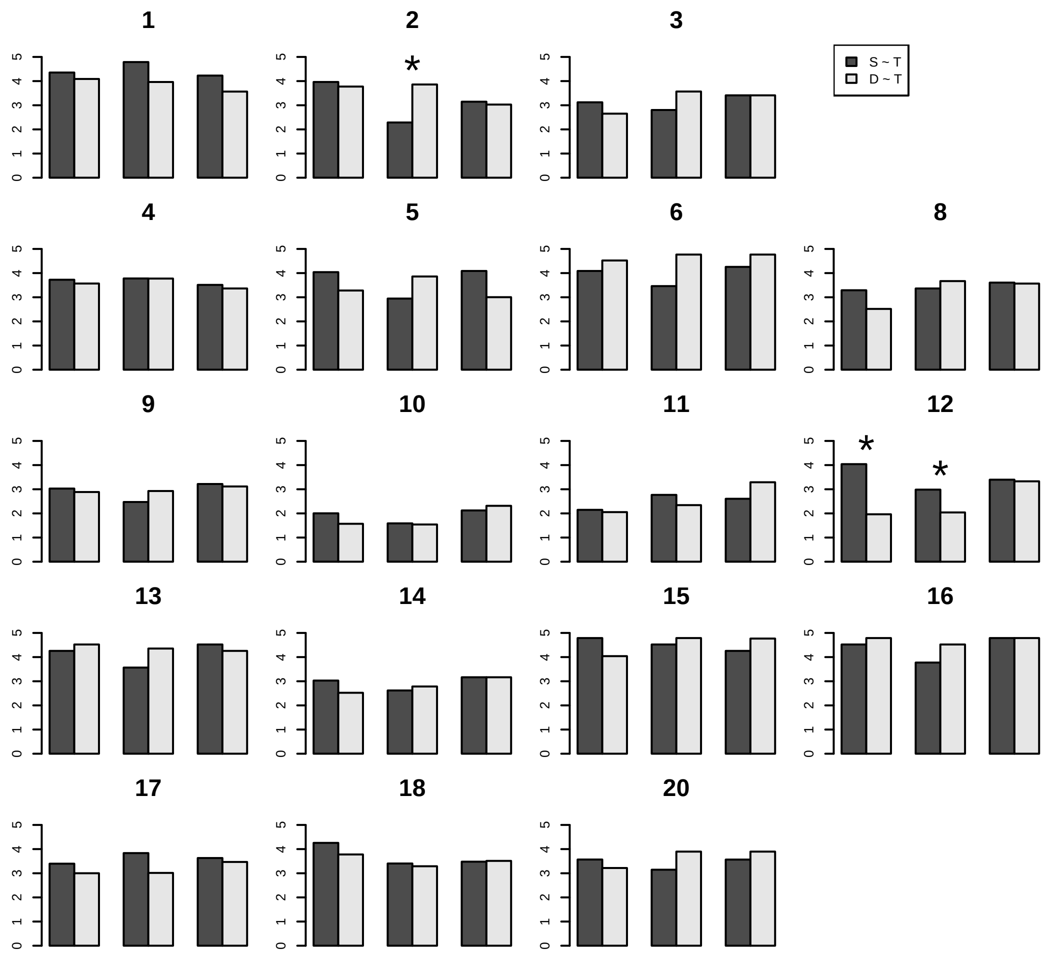


rate, section 4.3.3 below shows that inter-talker differences did not appear to have a large effect on subjects' performance.

'Same'-'Different' Responses

Figure 4.16 shows sensitivity to the S $\sim$ T and D $\sim$ T differences, broken down by subject. In contrast to the results for Experiment 2, neither difference is clearly more perceptible than the other. 11 subjects have a larger d' for S $\sim$ T than for D $\sim$ T; the difference is significant for two of them, subjects 12 and 17 (the latter also a native speaker of Cantonese). 7 subjects have a larger d' for D $\sim$ T than for S $\sim$ T; the difference is significant for two of them, subjects 2 and 6 (the former also a native speaker of Spanish). When the results are further broken down by place of articulation (shown in figure 4.17), we see a similar lack

Figure 4.17: Sensitivity to S $\sim$ T vs. D $\sim$ T by subject and place of articulation in Experiment 4. Stars mark within-subject and within-place differences that are significant at $\alpha = .05$. For each d', $194 \leq n \leq 213$. Within each plot, the three pairs of bars are for labials, coronals, and dorsals (left to right), and the y-axis measures d'



of an overall pattern, and only three differences are significant. However, it is interesting to note that for labials, the S $\sim$ T distinction is more salient than the D $\sim$ T distinction for the majority of subjects, although it is significant only for subject 12.

Figure 4.18: Sensitivity to S $\sim$ T vs. D $\sim$ T by talker and place of articulation for Experiment 4. Stars mark within-talker and within-place differences that are significant at $\alpha = .05$. For each d', $n = 1080$. Within each plot, the three pairs of bars are for labials, coronals, and dorsals (left to right), and the y-axis measures d'

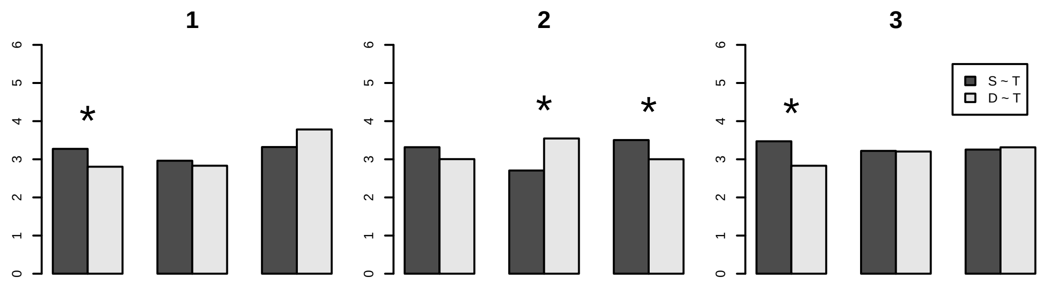
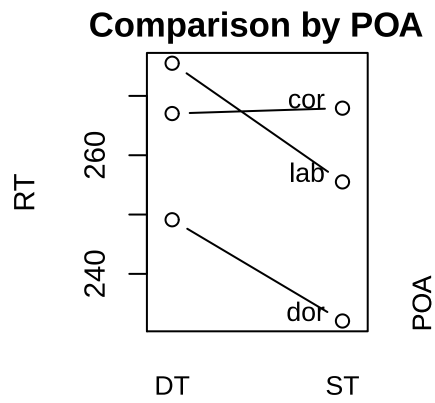


Figure 4.18 shows sensitivity by talker and place of articulation. Trends in both directions (S $\sim$ T more or less perceptible than D $\sim$ T) are seen for each talker; only some of the differences are significant. Note, however, that for both talkers 1 and 3, the difference is significant for labials; talker 2 has a non-significant trend in the same direction. These results, combined with the d' results in figure 4.17, constitute somewhat weak evidence that the [afa] $\sim$ [apa] distinction may be more salient than the [aba] $\sim$ [apa] distinction.

Reaction Times

Reaction times were analyzed in the same way as for Experiments 2 and 3. The effect of Comparison was not significant for coronals ($p = .31$) but approached significance for dorsals ($p = .093$) and labials ($p = .054$). For labials and dorsals, subjects responded more slowly to D $\sim$ T trials than to S $\sim$ T trials. Figure 4.19 shows the partial effects of the interaction between Comparison and Place. When bilingual subjects are excluded, the effect of Comparison is not significant at any

Figure 4.19: Partial effects of the interaction between Comparison and Place in Experiment 4



place ($p = .19$ for labials, .40 for coronals, and .16 for dorsals).

For reasons that are unclear to me, a large proportion of the responses in Experiment 4 (about 17%) were registered before the end of the second stimulus, in contrast to the less than 1% of responses in Experiment 2. Thus, many responses are excluded from the model described above because they involve negative reaction times. When reaction time is calculated from the end of the consonant, only just over 1% of responses are excluded in this way. The results of this model are comparable: responses are significantly slower to D $\sim$ T trials than to S $\sim$ T trials for labials ($p = .011$) and dorsals ($p = .023$), but not for coronals ($p = .21$). (When bilingual subjects are excluded, none of the differences are significant, but the difference for dorsals is nearly so; $p = .054$.)

4.3.3 Discussion

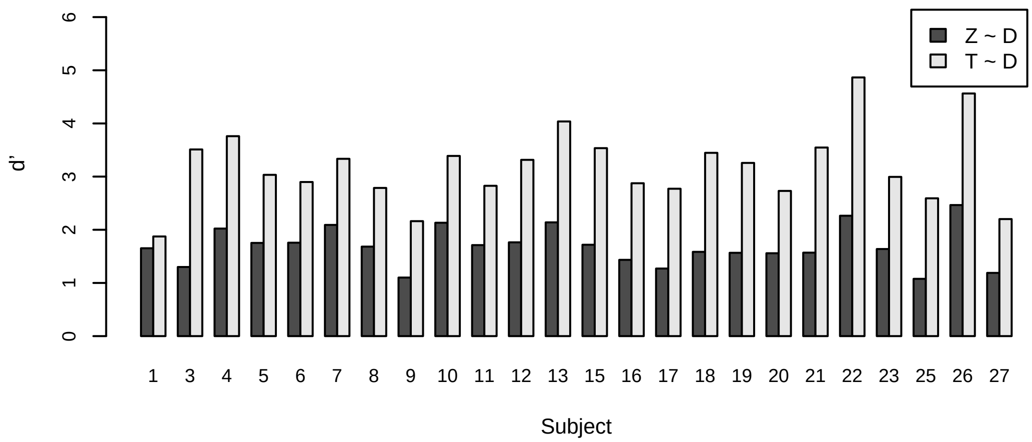
Overall Results

Unlike the results of Experiment 2, the results of Experiment 4 do not provide strong evidence for a large difference in perceptibility by comparison type. Subjects' sensitivity as measured by d' does not reveal a consistent difference between the D $\sim$ T comparison and the S $\sim$ T comparison; about half of the subjects have larger d's for each comparison, and the differences are significant for only a handful of subjects (some in each direction). However, there is some evidence that the S $\sim$ T comparison is more salient than the D $\sim$ T comparison for labials; the difference is significant for two of the three talkers, and 15 of the 18 subjects have trends in this direction.

The reaction time data suggests that the D $\sim$ T distinction may have been a bit more difficult for subjects to perceive than the S $\sim$ T distinction, especially for labials and dorsals; reaction times are slightly slower to the former trials than to the latter. However, the effect is much less robust than the difference by comparison type for Experiment 2; the differences are sometimes significant and sometimes not, depending on how reaction time is measured and which subjects are analyzed – factors that did *not* affect the main result for Experiment 2.

This constellation of results suggests that although there is a difference in perceptibility between the Z $\sim$ D and T $\sim$ D contrasts, there is no difference of a comparable magnitude between the S $\sim$ T and D $\sim$ T contrasts. However, it is possible that the lack of a robust result in Experiment 4 is due to its smaller sample size: for example, the d's in figure 4.16 are calculated from 540 observations each, while those in figure 4.3 are calculated from at least 600. To determine whether

Figure 4.20: Sensitivity to Z $\sim$ D vs. T $\sim$ D by subject in a subset of data from Experiment 2. Within-subject differences are non-significant at $\alpha = .05$ only for subject 1. For each d', $474 \leq n \leq 488$



Experiment 4 simply lacked the power to detect a difference in perceptibility as large as the one found in Experiment 2, I analyzed a random subset of the data from Experiment 2. For each subject and trial type (Z $\sim$ Z, D $\sim$ D, T $\sim$ T, Z $\sim$ D, and T $\sim$ D), I randomly selected 180 trials from Experiment 2 to include in the subset (the same as the number of trials for each subject and trial type in Experiment 4[8]). Thus, this subset of data represents what the results of Experiment 2 might have looked like if it had had the same power as Experiment 4. Figure 4.20 shows subjects' sensitivity in this 'smaller' Experiment 2; for every subject except subject 1, the difference between the Z $\sim$ D and T $\sim$ D comparison types is still significant. I conclude that Experiment 4 had ample power to detect a difference in perceptibility as large as the one found in Experiment 2.

[8]In many cases, there were fewer than 180 trials for a given subject and trial type in Experiment 2; in those cases, I included all of the relevant trials in the subset.

Effect of Acoustic Characteristics of Stimuli

In §4.3.2, I described four between-talker differences among the stimuli that might have influenced subjects' perception of the relevant contrasts: aspiration in the [aTa] stimuli; and consonant duration, center of gravity, and intensity in the [aSa] stimuli.

Greater aspiration in the [aTa] stimuli provides an extra cue to the voicing distinction and therefore may increase the perceptibility of the D $\sim$ T contrast. As shown in figure 4.12, the German- and English-speaking talkers produced more aspiration than the Bulgarian-speaking talker. However, subjects do not differ in sensitivity to the D $\sim$ T contrast for any of the three talkers ($d' = 3.0$ for talker 1, 3.2 for talker 2, and 3.1 for talker 3; none of the differences are significant). Alternatively, aspiration in the [aTa] stimuli might *decrease* the perceptibility of the S $\sim$ T contrast if subjects are likely to misperceive aspiration as frication noise or vice versa. However, the three talkers do not differ in sensitivity to the S $\sim$ T contrast either ($d' = 3.2$ for talker 1, 3.1 for talker 2, and 3.3 for talker 3; none of the differences are significant). Thus, it is unlikely that aspiration (or lack thereof) among some talkers is masking an effect of comparison type in Experiment 4.

As shown in figures 4.13 – 4.15, there are a number of differences among talkers at each place of articulation in the duration, center of gravity, and intensity of the voiceless fricatives; any of these differences has the potential to influence subjects' ability to perceive the S $\sim$ T contrast. Among all three talkers and all three places of articulation, there are only two cases in which two talkers differ significantly in subjects' sensitivity to the S $\sim$ T contrast at some place of articulation: subjects are significantly less sensitive to the [aθa] $\sim$ [ata] contrast for talker 2 ($d' = 2.6$) than for either talker 1 ($d' = 3.0$; $p = .046$) or talker 3 ($d' = 3.2$; $p = 2.0 \times 10^{-3}$). This difference might be attributable to talker 2's particularly short and intense [θ]s, although we cannot be certain.

It is possible, then, that the significant difference in sensitivity between [aθa] $\sim$ [ata] and [ada] $\sim$ [ata] that subjects exhibited for talker 2 is an anomaly. If so, then the only remaining significant effects in figure 4.18 would be cases where sensitivity to S $\sim$ T is smaller than sensitivity to D $\sim$ T, suggesting that the latter truly is the more salient distinction. However, even eliminating this significant effect would not eliminate all of the variability seen in the d' results, nor would it render the difference (if real) by comparison type large enough to be of comparable magnitude to the one found in Experiment 2. Thus, talker-particular characteristics of the voiceless fricatives in the [aSa] stimuli do not seem to be masking a large overall effect of comparison type in Experiment 4.

Effect of English Consonant Inventory

On the basis of the English consonant inventory, we would expect there to be an effect of comparison type among dorsals: subjects should be more sensitive to the [aga] $\sim$ [aka] contrast (phonemic in English) than to the [axa] $\sim$ [aka] contrast (since English lacks [x]). Interestingly, the results broken down by place in figures 4.17 and 4.18 show no such effect. This lack of a result suggests that the experimental task may have influenced subjects to tap into more fine-grained phonetic differences and to be less influenced by their native inventory.[9] Alterna-

[9]It is also possible that Experiment 4 lacked the power to detect a difference that was actually present among dorsals. As discussed above, this experiment had ample power to detect differences of the magnitude found in Experiment 2; thus, any difference among dorsals that did

tively, subjects may have assimilated [x] to a native category other than [k] (Best et al. 1988).

For labials and coronals, however, both comparison types are on equal footing: [p], [b], [f], [t], [d], and [θ] are all phonemic in English. Any difference by comparison type for labials or coronals *must* have been due to inherent differences in perceptibility between the continuancy and voicing contrasts (modulo talker-specfic effects). No such consistent differences were found.

4.4 Discussion and Implications

The results of Experiment 2 show that the distinction between voiced and voiceless stops intervocalically is perceptually more salient than the distinction between voiced stops and spirants in the same environment. This finding suggests that a perceptual account of the direction of lenition along the lines of the P-map is viable: we could hypothesize that intervocalic devoicing is unattested because intervocalic spirantization is perceptually a better (less salient) option.

The results of Experiment 4 show that there is no difference of a comparable size in perceptibility between voiced and voiceless stops vs. voiceless stops and fricatives intervocalically. This finding, too, is compatible with the P-map: voiceless stops may undergo lenition *either* by voicing *or* by spirantization, because neither alternation is perceptually superior to the other. (See §5.1 for a discussion of the implications of a possible small difference in comparison type among labials.)

The results of Experiment 3 show that for voiced stops, the difference in per-

not show up in the present results must be relatively small.

ceptibility between the continuancy and voicing distinctions is modulated by place of articulation: the effect of comparison type is greater for dorsals, for example, than it is for labials. If the implications of this perceptual fact for phonological theory are analogous to those for the facts shown by Experiment 2, then we should predict that spirantization of labials (a more salient change) implies spirantization of dorsals (a less salient change, and therefore to be preferred). However, as discussed in §2.2, this prediction is not borne out: if anything, spirantization of labials is *more* common than spirantization of dorsals. Table 2.8 shows that spirantization of labials does not imply spirantization of dorsals; there are ten languages in the database that spirantize labials only (Apatani, Assamese, Bashkir, Dahalo, Cardiff English, Kagate, Nepali, Nkore-Kiga, Ayt Seghrouchen Tamazight Berber, and Chitwan Tharu).

Thus, Experiments 2 – 4 make some correct predictions with respect to phonological typology and some incorrect ones. Chapter 5 discusses the implications of these results for phonological theory.

Chapter 5

Implications for Phonology

This chapter investigates how the results of the previous experiments might be incorporated into phonological theory. I adopt Optimality Theory (Prince and Smolensky 2004[1993]) in order to facilitate comparison with the typology: from its inception, OT has had as one of its explicit goals the ability to generate all and only attested types of natural languages. Ideally, the 'factorial typology' of a given set of constraints (that is, the set of all language types that can be generated by some ranking of those constraints) should correspond exactly to the set of attested language types.

5.1 Perception: Results of Experiments 2 – 4

5.1.1 The P-Map

As discussed in chapter 4, the P-map (Steriade 2001a,b) is a theory of the relationship between the perceptibility of a given contrast and the ability of the members of that contrast to alternate in a phonological pattern. Differences in perceptibility are translated into universal rankings of OT faithfulness constraints via the P-map, a database that encodes the relative perceptibility of various pairs of contrasts in various environments. Faithfulness constraints are ranked according to the perceptual distance between the underlying forms that they apply to and the output forms that would result if they were violated, with constraints against more perceptible changes to the underlying form ranked above constraints against less perceptible changes.

In a strict interpretation, the P-map predicts that every difference in perceptibility found in Experiments 2 – 4 should map to a ranking of faithfulness constraints, and therefore to a gap in the typology (that is, the repairs corresponding to the higher-ranked constraints should be unattested). The following sections explore whether this prediction is confirmed.

5.1.2 Effects of Voicing and Manner

The main result of Experiment 2 was that the contrast between voiced and voiceless stops is easier to perceive than the contrast between voiced stops and voiced spirants. This fact translates into the following constraint ranking:

(1) Ident[+voi]/V[___, –cont]V ≫
Ident[–cont]/V[___, +voi]V

Ident[+voi]/V[___, –cont]V requires faithfulness to an underlying [+voi] feature for intervocalic noncontinuants. Similarly, Ident[–cont]/V[___, +voi]V requires faithfulness to an underlying [–cont] feature for voiced segments. I use these highly context-specific constraints in order to limit the domain of discussion to those contexts for which Experiments 2 – 4 provide evidence; see §5.1.4 for discussion of the need to distinguish faithfulness constraints for a given feature according to the underlying value of that feature.

This main result correctly predicts that it is possible to have an alternation by which voiced stops are realized as voiced spirants intervocalically, but not one by which they are realized as voiceless stops intervocalically.

(2) *VDV ≫ IDENT[–cont]: spirantization

/aba/	IDENT[+voi]	*VDV	IDENT[–cont]
[aba]		*!	
☞ [aβa]			*
[apa]	*!		

(3) IDENT[–cont] ≫ *VDV: no change

/aba/	IDENT[+voi]	IDENT[–cont]	*VDV
☞ [aba]			*
[aβa]		*!	
[apa]	*!		

(The relevant environments are assumed but omitted from the IDENT constraints in these tableaus. *VDV stands in for the constraint(s) driving some repair to intervocalic voiced stops; see §5.2 for a proposal based on the results of Experiment 1.) If *VDV outranks IDENT[–cont], as in (2), the result is a language with intervocalic spirantization of voiced stops. If IDENT[–cont] outranks *VDV, as in (3), the result is a language in which intervocalic voiced stops are realized faithfully. Since the ranking IDENT[+voi] ≫ IDENT[–cont] is fixed by the perceptual facts, no other patterns are possible: in particular, it is not possible to have intervocalic devoicing of voiced stops.

In contrast to Experiment 2, Experiment 4 found little or no evidence for a difference in perceptibility between the contrast between voiced and voiceless stops and between voiceless stops and spirants. If the two contrasts really are equally perceptible, then the P-map should not project a universal ranking between IDENT[–voi]/V[___, –cont]V and IDENT[–cont]/V[___, –voi]V.

(4) *VTV, IDENT[–voi] ≫ IDENT[–cont]: spirantization

/apa/	*VTV	IDENT[–voi]	IDENT[–cont]
[apa]	*!		
☞ [afa]			*
[aba]		*!	

(5) *VTV, IDENT[–cont] ≫ IDENT[–voi]: voicing

/apa/	*VTV	IDENT[–cont]	IDENT[–voi]
[apa]	*!		
[afa]		*!	
☞ [aba]			*

(6) IDENT[–voi], IDENT[–cont] ≫ *VTV: no change

/apa/	*IDENT[–voi]	IDENT[–cont]	*VTV
☞ [apa]			*
[afa]		*!	
[aba]	*!		

The surface pattern depends on which constraint is ranked lowest. If the lowest-ranked constraint is IDENT[–cont], the result is spirantization; if it is IDENT[–voi], the result is voicing; if it is *VTV, there is no change. Since the ranking between the two IDENT constraints is not fixed, this analysis correctly predicts that both spirantization and voicing are possible.

However, recall that Experiment 4 did provide some weak evidence that spirantization might be a slightly more perceptible change for intervocalic voiceless stops than voicing, especially for labials. If there really is a difference between the two contrasts, then in order for the P-map to remain viable it must be able to avoid projecting a universal ranking such as IDENT[–cont] ≫ IDENT[–voi], which would incorrectly predict that intervocalic voiceless stops may voice but not spirantize. One solution might be to appeal to the fact that the difference between the Z $\sim$ D and T $\sim$ D contrasts found in Experiment 2 was much larger than the difference between S $\sim$ T and D $\sim$ T found in Experiment 4. Perhaps faithfulness constraints are only projected when the difference in perceptibility between two contrasts crosses some threshold; the difference between Z $\sim$ D and T $\sim$ D is sufficiently large, but the difference between S $\sim$ T and D $\sim$ T is not. Although plausible, this approach remains an ad-hoc solution until we find independent evidence for such a threshold. The question of how to prevent the P-map from overgenerating universal rankings among faithfulness constraints is taken up again in §5.1.4.

For the sake of discussion, I will assume that there is no difference in perceptibility between voicing and spirantization for underlying voiceless stops, but I acknowledge that the data is somewhat equivocal on this point. Interestingly, although both voicing and spirantization are attested alternations for intervocalic voiceless stops, voicing seems to be the more common option: as shown in table 2.1, 26 languages in Gurevich's (2004) database of lenition have voicing of voiceless stops, while only 17 have spirantization of voiceless stops. (The difference, however, is not significant; $p = .18$.) Perhaps differences in perceptibility that are too small to be projected as universal rankings among faithfulness constraints are still able to influence typological frequency. Indeed, it is possible that 'hard' typological patterns such as the absence of intervocalic devoicing are simply extreme cases of the type of 'soft' tendency seen here. I leave this very interesting line of investigation to future research.

5.1.3 Effect of Place of Articulation

Experiment 3 showed that the perceptibility of contrasts involving voiced and voiceless stops or voiced stops and spirants interacts with place of articulation. For the voicing contrast, the reaction time data presented in §4.2.2 suggests that the difference between [b] and [p] intervocalically is the most difficult to perceive, while the difference between [d] and [t] is the easiest. This fact translates into the following ranking:

(7) IDENT[–voi]/V[___, –cont, cor]V ≫
IDENT[–voi]/V[___, –cont, dor]V ≫
IDENT[–voi]/V[___, –cont, lab]V

If universal, this ranking predicts that intervocalic voicing can only apply to certain combinations of voiceless stops. If *VTV is undominated, then intervocalic voicing applies across the board:

(8) *VTV ≫
IDENT[–voi]/V[___, cor]V,
IDENT[–voi]/V[___, dor]V,
IDENT[–voi]/V[___, lab]V:
intervocalic voicing of labials, coronals, and dorsals

/apa/ /ata/ /aka/	*VTV	IDENT/[cor]	IDENT/[dor]	IDENT/[lab]
☞ [aba] [ada] [aga]		*	*	*
[aba] [ada] [aka]	*!	*		*
[aba] [ata] [aga]	*!		*	*
[aba] [ata] [aka]	*!*			*
[apa] [ada] [aga]	*!	*	*	
[apa] [ada] [aka]	*!*	*		
[apa] [ata] [aga]	*!*		*	
[apa] [ata] [aka]	*!**			

If *VTV outranks only the IDENT constraints for dorsals and labials, then only /p/ and /k/ are subject to intervocalic voicing:

(9) IDENT[–voi]/V[___, cor]V ≫
*VTV ≫
IDENT[–voi]/V[___, dor]V,
IDENT[–voi]/V[___, lab]V:
intervocalic voicing of labials and dorsals

/apa/ /ata/ /aka/	IDENT/[cor]	*VTV	IDENT/[dor]	IDENT/[lab]
[aba] [ada] [aga]	*!		*	*
[aba] [ada] [aka]	*!	*		*
☞ [aba] [ata] [aga]		*	*	*
[aba] [ata] [aka]		**!		*
[apa] [ada] [aga]	*!	*	*	
[apa] [ada] [aka]	*!	**		
[apa] [ata] [aga]		**!	*	
[apa] [ata] [aka]		**!*		

If *VTV outranks only the IDENT constraint for labials, then only /p/ is subject to intervocalic voicing:

(10) IDENT[–voi]/V[___, cor]V,
IDENT[–voi]/V[___, dor]V ≫
*VTV ≫
IDENT[–voi]/V[___, lab]V:
intervocalic voicing of labials

/apa/ /ata/ /aka/	Ident/[cor]	Ident/[dor]	*VTV	Ident/[lab]
[aba] [ada] [aga]	*!	*		*
[aba] [ada] [aka]	*!		*	*
[aba] [ata] [aga]		*!	*	*
☞ [aba] [ata] [aka]			**	*
[apa] [ada] [aga]	*!	*	*	
[apa] [ada] [aka]	*!		**	
[apa] [ata] [aga]		*!	**	
[apa] [ata] [aka]			***!	

Finally, if *VTV ranks below all three Ident constraints, then no intervocalic voicing occurs:

(11) Ident[–voi]/V[___, cor]V,
Ident[–voi]/V[___, dor]V ≫
Ident[–voi]/V[___, lab]V ≫
*VTV:
no intervocalic voicing

/apa/ /ata/ /aka/	Ident/[cor]	Ident/[dor]	Ident/[lab]	*VTV
[aba] [ada] [aga]	*!	*	*	
[aba] [ada] [aka]	*!		*	*
[aba] [ata] [aga]		*!	*	*
[aba] [ata] [aka]			*!	**
[apa] [ada] [aga]	*!	*		*
[apa] [ada] [aka]	*!			**
[apa] [ata] [aga]		*!		**
☞ [apa] [ata] [aka]				***

No other patterns are possible: intervocalic voicing of coronals implies voicing of dorsals, and voicing of dorsals implies voicing of labials. However, Gurevich's database contains three counterexamples to these generalizations: Périgourdin French voices [t] only, Apalai voices [k] only, and Lotha voices [t] and [k] only. Thus, for differences by place of articulation, the predictions of the P-map are not borne out.

Experiment 3 also showed that for the continuancy contrast, the difference between [g] and [ɣ] intervocalically is the most difficult to perceive. This fact translates into the following ranking:

(12) IDENT[–cont]/V[___, lab]V,
IDENT[–cont]/V[___, cor]V ≫
IDENT[–cont]/V[___, dor]V

As with intervocalic voicing, these differences by place make predictions about possible patterns of intervocalic spirantization. If *VDV is undominated, then intervocalic spirantization applies across the board:

(13) *VDV ≫
IDENT[–cont]/V[___, lab]V,
IDENT[–cont]/V[___, cor]V,
IDENT[–cont]/V[___, dor]V:
intervocalic spirantization of labials, coronals, and dorsals

/aba/ /ada/ /aga/	*VDV	IDENT/[lab]	IDENT/[cor]	IDENT/[dor]
☞ [aβa] [aða] [aɣa]		*	*	*
[aβa] [aða] [aga]	*!	*	*	
[aβa] [ada] [aɣa]	*!	*		*
[aβa] [ada] [aga]	*!*	*		
[aba] [aða] [aɣa]	*!		*	*
[aba] [aða] [aga]	*!*		*	
[aba] [ada] [aɣa]	*!*			*
[aba] [ada] [aga]	*!**			

If *VDV is dominated only by the IDENT constraint for labials, then spirantization applies only to /d/ and /g/:

(14) Ident[–cont]/V[___, lab]V ≫
*VDV ≫
Ident[–cont]/V[___, cor]V,
Ident[–cont]/V[___, dor]V:
intervocalic spirantization of coronals and dorsals

	/aba/ /ada/ /aga/	Ident/[lab]	*VDV	Ident/[cor]	Ident/[dor]
	[aβa] [aða] [aɣa]	*!		*	*
	[aβa] [aða] [aga]	*!	*	*	
	[aβa] [ada] [aɣa]	*!	*		*
	[aβa] [ada] [aga]	*!	**		
☞	[aba] [aða] [aɣa]		*	*	*
	[aba] [aða] [aga]		**!	*	
	[aba] [ada] [aɣa]		**!		*
	[aba] [ada] [aga]		**!*		

Analogously, if *VDV is dominated only by the Ident constraint for coronals, then spirantization applies only to /b/ and /g/ (tableau not shown). If *VDV dominates only the Ident constraint for dorsals, then spirantization applies only to /g/:

(15) Ident[–cont]/V[___, lab]V,
Ident[–cont]/V[___, cor]V ≫
*VDV ≫
Ident[–cont]/V[___, dor]V:
intervocalic spirantization of dorsals

	/aba/ /ada/ /aga/	Ident/[lab]	Ident/[cor]	*VDV	Ident/[dor]
	[aβa] [aða] [aɣa]	*!	*!		*
	[aβa] [aða] [aga]	*!	*!	*	
	[aβa] [ada] [aɣa]	*!		*	*
	[aβa] [ada] [aga]	*!		**	
	[aba] [aða] [aɣa]		*!	*	*
	[aba] [aða] [aga]		*!	**	
☞	[aba] [ada] [aɣa]			**	*
	[aba] [ada] [aga]			***!	

Finally, if *VDV is dominated by all three IDENT constraints, no intervocalic spirantization occurs at all:

(16) IDENT[–cont]/V[___, lab]V,
IDENT[–cont]/V[___, cor]V,
IDENT[–cont]/V[___, dor]V ≫
*VDV:
no intervocalic spirantization

/aba/ /ada/ /aga/	IDENT/[lab]	IDENT/[cor]	IDENT/[dor]	*VDV
[aβa] [aða] [aɣa]	*!	*!	*	
[aβa] [aða] [aga]	*!	*!		*
[aβa] [ada] [aɣa]	*!		*	*
[aβa] [ada] [aga]	*!			**
[aba] [aða] [aɣa]		*!	*	*
[aba] [aða] [aga]		*!		**
[aba] [ada] [aɣa]			*!	**
☞ [aba] [ada] [aga]				***

No other patterns are possible. Because of the rankings fixed by the P-map, spirantization of either labials or coronals implies spirantization of dorsals. Again, though, this prediction does not match the typology. Gurevich's database contains 14 languages with spirantization of labials but not dorsals (Apatani, Assamese, Bashkir, Dahalo, Cardiff English, Kagate, Nepali, Nkore-Kiga, Ayt Seghrouchen Tamazight Berber, and Chitwan Tharu) or coronals but not dorsals (Purki Balti, Dahalo, Périgourdin French, and Purki). For intervocalic spirantization as well, the predictions of the P-map are not confirmed.

5.1.4 Which Faithfulness Constraints Are Projected?

As originally formulated, the P-map appears to be intended to project universal rankings between faithfulness constraints automatically for every difference in perceptibility between two contrasts:

> For *any* two P-map cells, x – y/___K_i and w – z/___K_j, if x – y/___K_i ➢ w – z/___K_j then *any* correspondence constraint referring to x – y/___K_i outranks *any* parallel constraint referring to w – z/___K_j.
>
> Steriade (2001a, 28, emphasis added)

('➢' denotes 'is more perceptible than'. Parallel correspondence constraints are faithfulness constraints regulating the relationship between the same two representations – IO, OO, BR, etc.) As shown in the previous section, if we project universal faithfulness constraints from *all* of the perceptual results of Experiments 2 – 4, the result is a mixed bag: we make some correct predictions (no intervocalic devoicing) and some incorrect predictions (differences by place of articulation). There are at least two ways to respond to this constellation of results:

1. Conclude that the theory of the P-map is ultimately incorrect. Those cases where the P-map appears to make the correct predictions (such as final devoicing) are due to chance.

2. Allow the database of perceptibility differences to project only rankings of faithfulness constraints that match typological facts.

The P-map *does* appear to make correct predictions in a range of cases – in addition to final devoicing, it has been applied to consonant cluster simplification and epenthesis of [ʔ] and [ə] (Steriade 2001a), the directionality of consonant assimilation (Steriade 2001b), the behavior of voicing in singleton and geminate stops (Kawahara 2006), and laryngeal co-occurrence restrictions (Gallagher 2009). Thus, it seems unwise to reject the P-map entirely until it is clear that a better solution cannot be found.

In addition, restricting the constraint rankings that are projected by the database of perceptibility differences seems desirable independent of these facts. It is unlikely that *every* pair of possible changes to a given input should be associated with a universal constraint ranking. For example, if we were to compare the perceptibility of final devoicing to that of the alternations involved in vowel harmony, it is entirely possible that we would find a difference – and yet the two processes may occur independently. But restricting how constraints are projected is a viable option only if we can find a principled way to do so: simply stipulating that rankings that do not match the typology are not projected only restates the problem. Determining what, if any, restrictions should be placed on how constraint rankings are projected is a project beyond the scope of this dissertation; it ultimately requires us to compare the perceptibility of each possible change for each possible input with every other possible change, and to match those results to the typological facts. However, I will offer some preliminary discussion here, based on the data at hand.

One way in which the universal rankings in (7) and (12) (those that yield problematic predictions for by-place differences in lenition) are different from the one in (1) (whose predictions are correct) is that the constraints within each of the former sets do not apply to the same underlying segments. That is, one constraint in each set applies to labial segments, another to coronal segments, and another to dorsal segments. The original purpose of the P-map, however, was to explain how languages choose among various possible repairs to the *same* marked configuration. The universal ranking in (1) accomplishes this goal: for a given intervocalic voiced stop, the ranking favors spirantization over voicing. The rankings in (7) and (12), however, do not: because the segments to which the constraints in each IDENT family apply are disjoint, only one constraint in each family may apply to a given underlying intervocalic voiced stop. Thus, the rankings in (7) and (12) entail implicational relationships among repairs to *different* marked configurations, rather than determining which repair is chosen for a *single* marked configuration.

Therefore, to avoid the undesired rankings of (7) and (12), we might impose a restriction on the projection of rankings from the P-map: a universal ranking between two faithfulness constraints may only be projected if the two constraints regulate competing repairs for the same markedness constraint for some string of segments. IDENT[+voi]/V[___]V and IDENT[–cont]/V[___]V both regulate potential repairs to sequences that violate *VDV (devoicing and spirantization); therefore, the P-map can licitly project a universal ranking between the two. However, the situation is different for the place-specific IDENT constraints. There is no single string of segments such that IDENT[–cont]/V[___, lab]V and IDENT[–cont]/V[___, cor]V represent two alternative pairs for the same markedness violation: the former applies only to intervocalic labials, while the latter applies only to intervocalic coronals.[1] Thus, the P-map cannot licitly project a universal ranking between the two (or between any of the place-specific constraints considered above), and the problematic rankings in (7) and (12) are ruled out.

[1] Leaving aside the treatment of segments with multiple places of articulation, e.g., labiovelars.

Clearly, more research is required to determine whether this approach is borne out when we examine more types of repairs. In the meantime, it has the benefit of making a principled distinction in this particular case between those predictions of the P-map that appear to be correct and those that we should avoid.

Note that this restriction on the projection of rankings by the P-map also requires that we distinguish among faithfulness constraints that regulate a given feature on the basis of the underlying value of that feature; it is for this reason that I distinguish between constraints such as Ident[+voi] and Ident[–voi]. Ident[+voi] regulates changes in voicing to underlyingly voiced stops (a possible repair for violations of *VDV), while Ident[–voi] regulates changes in voicing to underlyingly voiceless stops (a possible repair for violations of *VTV).

5.2 Production: Results of Experiment 1

5.2.1 Previous Models of Articulatory Effort

As noted in chapter 3, attempts to link articulatory effort and phonological patterns are ubiquitous. This section reviews a sample of research that incorporates articulatory effort into formal phonological models. Note that the authors whose work is reviewed here would probably not claim that their particular proposals are the only or even the best way to account for articulatory effort; this overview is meant only to be representative.

Pater, Hayes, and Kirchner

Pater (2004[1999]) documents a range of processes in several languages that have the effect of eliminating a sequence of a nasal followed by a voiceless stop. Working within Optimality Theory, he proposes a markedness constraint *N$\underset{\circ}{\mathrm{C}}$ penalizing such sequences and notes that there is evidence that these sequences should be articulatorily disfavored; in particular, Ohala and Ohala (1991, 213[2]) argue that nasal leakage in the first part of the segment is compatible with voiced stops but not voiceless ones.

Hayes (2004[1999]) investigates the status of stop voicing in a number of environments. He derives scores of articulatory effort from Westbury and Keating's (1986) aerodynamic model of the vocal tract and proposes an algorithm for generating markedness constraints that attempts to balance the need for constraints to penalize difficult configurations with the need for constraints to be general and maintain formal symmetry. The result is a set of constraints, including constraints against post-nasal and -sonorant voiceless stops, that correspond well to cross-linguistic patterns of favored and disfavored structures.

Kirchner (2001b) develops a mass-spring model of the vocal tract that assigns a difficulty to a given configuration based on the force exerted throughout the relevant gestures in order to move the required articulators. He posits a LAZY constraint penalizing structures that require more force relative to those that require less force. Among other predictions, the model identifies geminates as more effortful than singletons; thus, LAZY favors degemination. (Kirchner also identifies intervocalic voiced stops as more effortful than their voiceless counterparts, using the same aerodynamic model as Hayes.)

[2]The page number cited by Pater, 273, appears to be a typographical error.

In all three of these accounts, the basic approach involves comparing two members of a phonological contrast (in a particular segmental context) and identifying one member of the contrast as the one that requires more articulatory effort. Con is assumed to contain at least one markedness constraint penalizing the more effortful configuration relative to the less effortful one. However, the results of Experiment 1 do not provide a good match to this type of account. Recall that the dominant pattern of that experiment was not one in which subjects favored one member of a constrast over another (voiced vs. voiceless stops or stops vs. spirants); rather, the common denominator across subjects and segment types was a contraction of the articulatory space such that *both* members of a given opposition moved toward each other. Thus, at least for the segments and environments examined in Experiment 1, articulatory effort minimization does *not* appear to favor one member of a contrast over another. This pattern is unlike that of the analyses of Pater, Hayes, and Kirchner.

Lindblom

Lindblom (1983) makes the case for a general principle of gestural economy in speech, arguing for a wide range of phonetic and phonological patterns that they can be viewed as involving articulatory effort reduction. He places a special emphasis on articulator movement and proposes the mass-spring model developed further by Kirchner (2001b) as a way of quantifying a positive correlation between distance moved by a given articulator and effort expended.

In examining vowels, Lindblom reviews experimental evidence that formant values are related to vowel duration: the shorter the vowel, the less likely it is that its formants will reach their targets. Lindblom interprets this result as reduction of the relevant gesture; when the vowel is short, there is less time for the articulator to reach its target, and the result is gestural 'undershoot'.

The results of Experiment 1 can be interpreted as consistent with Lindblom's proposal that effort reduction leads to gestural undershoot. It is a small step to say that the compression of the articulatory space that was observed across subjects and segment types is a case of undershoot: when subjects are intoxicated, they are less able to execute the full articulatory movement required for a given sound; as a result, extreme gestures of all types are reduced, and the differences between contrasting sounds become smaller. However, the crucial factor determining the degree of undershoot in Experiment 1 is *not* duration of the relevant segment;[3] rather, most important is whether the subject was intoxicated. Indeed, segments were simultaneously *longer* in the intoxicated condition *and* exhibited more undershoot. Thus, while Lindblom's articulatory undershoot seems to provide a good match to the pattern observed in intoxicated speech in Experiment 1, the particular factor he examines (segment duration) is clearly not the relevant one here.

Flemming

Flemming (2002), in his development of Dispersion Theory, proposes three basic and opposing forces that jointly determine the distribution of sounds in a language: the desires to maximize the number of contrasts in a phonological system, to maximize how auditorily distinct those contrasts are from one another, and to minimize articulatory effort. Because his focus is on the role of perception,

[3]Lindblom himself acknowledges (1983; 1990) that segment duration is not the sole or even the most important determinant of whether undershoot occurs, at least in vowels.

he does not formalize any systematic hypotheses as to which segments require more articulatory effort than others; however, he generally assumes (e.g., pg. 16) that the closer a segment is to the periphery of the auditory space, the more effort it requires. Like Lindblom's (1983) proposal, Flemming's is consistent with the results of Experiment 1: intoxicated subjects exhibited contraction of the articulatory space, avoiding extremes for all members of a given contrast.

Under Flemming's account, a language will have segments near the edge of the auditory space only if it must do so in order to maintain a contrast. For example, if a language has a backness contrast for vowels, then its inventory will contain both front vowels (like [i]) and back vowels (like [u]). However, if a language does not have a backness contrast, then its vowels will be neither front nor back, but central (like [ɨ]), possibly subject to variation depending on the segmental environment. This account correctly predicts that 'vertical' vowel inventories, as in Kabardian (Gordon and Applebaum 2010), will involve central vowels rather than front or back ones. Flemming accomplishes this by positing a family of MinDist constraints that require distinct segments to be separated by a certain amount in the auditory space. Since MinDist constraints only apply to phonologically contrastive forms, there is no reason for forms that do *not* contrast to occupy anything but the middle of the auditory space. Thus, the dispersion (or lack thereof) of a given articulatory dimension is related to whether that dimension is used to signal some phonological contrast.

To apply Dispersion Theory to the present results, we must say that intoxication promotes constraints banning 'extreme' articulatory gestures over some MinDist constraints. This account requires that any auditory dimension that exhibits contraction in the intoxicated condition must be used to signal some contrast. Otherwise, there would be no reason for segments to be dispersed along that dimension in the first place; at most, we would see random dispersion due to noisy implementation of the relevant gestures independent of any particular contrast. All of the measurements tested in Experiment 1 showed contraction; therefore, we predict that all of these dimensions are used to signal at least one phonological constrast.

Table 5.1 shows the relationship in Experiment 1 between compression of various dimensions in the intoxicated condition and the use of those dimensions to signal phonological contrast. A gray cell for a given subject and measurement means that that subject exhibited compression along that dimension. A short line segment in the cell denotes a significant difference for some contrast along the dimension in question. A horizontal line means that there is a significant difference between voiced and voiceless stops for that dimension. A vertical line indicates some significant difference by place for that dimension: a line on the left shows a contrast between labials and coronals, a line in the center a contrast between labials and dorsals, and a line on the right a contrast between coronals and dorsals.[4] For significant differences by voicing or place, Holm's correction for multiple comparisons was applied within, but not across, rows (separately for voicing and for place).

A naïve application of Dispersion Theory to Experiment 1 would expect to see two types of cells in table 5.1: cells with *both* compression *and* a significant cue to contrast, and cells with *neither* compression *nor* a significnat cue to contrast. Cells with compression but no contrast, or vice versa, are unexpected. However, as

[4]The position of these lines for place of articulation is meant to be iconic. In a mid-saggital section of the oral tract viewed from the left, the front of the mouth is on the left and the back is on the right.

Table 5.1: Articulatory compression and cues to phonological contrast. A gray cell denotes a regression line with a slope significantly different from 0 and 1. A horizontal line denotes a significant difference between voiced and voiceless stops. A vertical line denotes a significant difference by place: labial-coronal on the left, labial-dorsal in the center, and coronal-dorsal on the right.

Measure	**Subject**							
	00	**01**	**02**	**03**	**04**	**05**	**06**	**07**
Nasal-Stop Stimuli								
Dur. consonant (from V)	├─	│ │	││	├┼	│││	│ │	│││	│││
Dur. consonant (from N)	─	─┤	├─	├┼	├─┤	├─┤	├─┤	├─┤
Dur. voicing (from V)	─	─	─	─	─	─	├┼	─
Dur. voicing (from N)	│		─	├┼	─		─	
Prop. closure voiced (from V)	├─┤	─	─	├─	─	├─	─	├─
Prop. closure voiced (from N)	─	─┤	─	─	─┤	─	├─┤	─
Lenition Stimuli								
Dur. consonant	├─┤	├┼┤	├┼┤	├┼┤	├┼┤	├┼┤	├┼┤	├┼┤
Dur. voicing	─	─	─	├─	─	─	├─┤	─
Prop. closure voiced	├─┤	├─┤	├─┤	─	─	─┤	├─┤	├─┤
Dur. burst	│││	┼┤	├┼┤	├┼	├┼┤	┼┤	┼┤	├┼┤
Int. ratio, C/V1	││			│		─┤	│	│
Int. ratio, C/V2	││		│	─		│		│ │
Min. slope, int. contour	├┼┤	├─┤	├─┤	─		├─┤	│ │	├─┤
Max. slope, int. contour	├┼┤	├─┤	├─┤	├┼		├┼┤	│ │	├─┤

the table shows, both of these unexpected cases are in fact attested. (In addition, there are no cells with neither compression nor a significant contrast!) Let us consider the two types of unexpected cases in turn.

As discussed above, a dimension that shows compression but is not used to signal phonological contrast is unexpected because, if it is irrelevant to contrast, there is no reason for values along the dimension to be dispersed in the first place. There are seven cases of this type in table 5.1, for three auditory dimensions: the duration of voicing in nasal-stop stimuli as measured from the end of the nasal, the intensity of the consonant in lenition stimuli relative to the preceding vowel, and the intensity of the consonant in lenition stimuli relative to the following vowel. These examples may run counter to the most straightforward implications of Dispersion Theory, but we should not press them too far: after all, it is entirely possible that the differences in these cases were too small to be detected by Experiment 1, or that the dimensions in question are in fact used to signal some contrast other than voice or place. For the intensity of the consonant in lenition stimuli, it seems quite likely that we would find significant differences between sonorants and obstruents – a difference not seen here since all of the target consonants in Experiment 1 were obstruents. As for voicing duration in the nasal-stop stimuli, it is surprising that this dimension does not at least cue the voicing contrast! However, statistical power is a real concern for this measure; recall that a separate nasal could not be identified for all tokens.

A dimension that does not show compression but does signal contrast is unexpected because it would show that articulatory effort reduction does not apply to every dimension, or does not apply to every dimension to the same degree. Table 5.1 shows thirteen such cases, scattered across a range of dimensions and subjects.

Certainly, Dispersion Theory is compatible with the idea that the articulatory effort required to disperse sounds is different along different dimensions; or that intoxication affects various dimensions differently, interfering with dispersion for some dimensions but not for others. These cases, then, are like the previous group in being at least theoretically *consistent* with a Dispersion-Theoretic model, but not *explained* by it.

5.2.2 What Makes a Sound 'Effortful'?

As discussed in §3.1, and demonstrated by this brief survey, the literature contains many different views on what it is that makes a given segment (or sequence of segments) articulatorily 'effortful'. Many proposals appeal to biomechanical properties of the gestures involved: a sound is more effortful if the relevant articulator moves farther (Lindblom 1983) or faster (Uchanski 2005, 226), if it must be sustained or is 'tense' (Padgett 2009, 440), if it requires precise execution (Lavoie 2001, 166), or if is relatively 'unstable' when combined with the other gestures required for the sequence (Pouplier 2003). Kirchner's (2001a) mass-spring model attempts to combine several of these ideas; here, effort is defined as the total force exerted throughout a gesture; gestures that move faster or farther, that are longer, or that require several applications of force in order to maintain a precise position all require more total force than gestures that do not. In addition to these proposals, which focus primarily on the oral articulators, Westbury and Keating (1986), Ohala and Ohala (1991), and Hayes (2004[1999]) note the importance of aerodynamic considerations, especially for voicing.

I emphasize again that the results of Experiment 1 do not shed light on the question of *why* particular productions are effortful. Rather, the goal of Experiment 1 was to determine, if possible, *which* productions are more effortful than others; indeed, this is a necessary first step, since we cannot explain the relative difficulty of different productions if we do not know for certain what their relative difficulty is! Since alcohol affects the body in many ways (see §3.2), several of the above-mentioned hypotheses about articulatory difficulty could explain reduction induced by intoxication. For example, subjects might not be able to move their articulators as far or as fast, due to the overall depressive effect of alcohol; cognitive impairment might interfere with subjects' ability to maintain precise gestures or coordinate several gestures simultaneously.

5.3 Putting It All Together

This section offers a unified OT analysis of intervocalic spirantization and voicing that is faithful to the experimental results in the various ways discussed above. This proposal is not meant to be definitive, but rather illustrative. The most important result of this dissertation (especially Experiment 1) is that, when analyzing lenition, we can no longer do 'phonology as usual' – that is, Experiment 1 provides no support for constraints that simply favor the lenited form over the unlenited form. The following discussion illustrates what an analysis might have to look like in order to account for patterns like these *without* relying on constraints that simply say, "Lenite!"

5.3.1 Analysis of Intervocalic Lenition

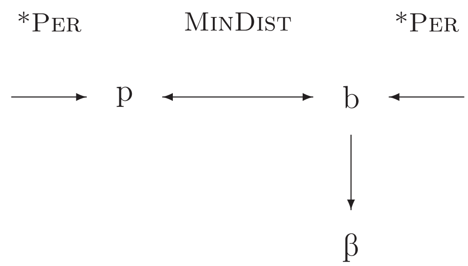
I argued in §5.2.1 that of extant proposals in the literature for modeling articulatory effort, Dispersion Theory (Flemming 2002; Padgett 2003; Ní Chiosáin and Padgett 2009; Padgett 2009)[5] is the closest match to the results of Experiment 1. The following analysis is therefore set within that framework. Dispersion Theory makes use of constraints that evaluate entire systems rather than individual forms; this is necessary because the theory explicitly controls systemic properties such as the phonetic distance between contrasting categories and the number of categories that contrast. Thus, the inputs and the candidates in a Dispersion-Theoretic analysis are idealized sets of forms rather than individuals.

Under my analysis, lenition occurs when effort reduction (represented by a high-ranking markedness constraint) encourages compression of some phonetic dimension (such as voicing), but compression is prevented by another markedness constraint that requires contrasting categories to be sufficiently dispersed along that dimension. To satisfy both constraints, one of two things must happen: either the contrast along that dimension collapses, or one of the two categories lenites by moving along a perpendicular dimension (such as continuancy). In other words, if articulatory effort reduction squeezes the voicing dimension for stops enough, either /p/ and /b/ will merge or one of the two will pop out of the dimension, becoming a spirant. Figure 5.1 sketches how the basic idea applies to spirantization; the constraints named in the figure are discussed in more detail below.

Note that this account requires the grammar to be able to refer to, and regu-

[5] See also Boersma and Hamann (2008) for a similar analysis which assumes that peripheral productions are articulatorily difficult.

Figure 5.1: Sketch of analysis of spirantization



late, subphonemic differences within categories. For example, if [b] lenites to [β] because effort reduction encourages its voicing value to decrease just slightly – bringing it a little too close to [p] but not making it a different category – then constraints must be able to refer to more fine-grained differences in voicing duration than are provided by categories that are known to contrast, such as [p] and [b]. My solution (which, again, I view as preliminary and not definitive) is to have inputs consist of discrete categories – as a first approximation, the categories defined by IPA symbols. Outputs, on the other hand, specify those categories for more fine-grained phonetic detail. Thus, while an input might contain the segment /b/, an output might contain a segment [b] with 50 ms of voicing.

I also make the simplifying assumption that the boundaries of the phonetic space, both its extreme edges and its internal category divisions, are determined by Gen. For example, I assume below that a stop can have between 0 and 60 ms of voicing, and that a voiceless stop is one with less than 20 ms of voicing and a voiced stop has more than 20 ms of voicing. (These values correspond roughly to the behavior of the majority of subjects in Experiment 1.) This is obviously a simplification: not only is there variation *between* subjects with respect to the amount of voicing they produce for different stops, but also *within* subjects the distributions of voicing values for voiced and voiceless stops overlap. One way to account for this inter- and intra-subject variation would be to put these boundaries under the control of constraints.

My analysis uses the following constraints:

- *Merge requires forms that contrast in the input to contrast in the output. Individual input and output forms are linked by a correspondence relation separate from the one that links individual segments. In the tableaux below, corresponding forms are indicated with capital letters when the correspondence is not obvious.

- MinDist constraints require that forms that contrast for a certain feature be separated on the relevant phonetic dimension by a certain distance. Usual practice in Dispersion Theory is to divide the phonetic space into a relatively small number of discrete units, usually corresponding to attested phonemic categories (Flemming 2002; Ní Chiosáin and Padgett 2009), and posit a corresponding family of universally ranked MinDist constraints. For example, suppose F1 is divided into five abstract parts corresponding to the heights of [i], [ɪ], [e], [ɛ], and [æ]. Then MinDist[F1][4] requires that any two vowels contrasting in height be separated by at least 4 units in the F1 space; this constraint would be satisfied by a contrast between [i] and [æ], but by no other pair of front vowels. MinDist[F1][3] is less strict, requiring a distance of only 3 units, and is satisfied by pairs such as [i] and [ɛ]. MinDist constraints are usually assumed to be universally ranked from least to most strict; however, since these constraints are in a strigency relationship, this is not strictly necessary (de Lacy 2002).

Rather than dividing the phonetic space into a small number of abstract categories, the MinDist constraints below refer directly to phonetic dimensions. Thus, MinDist[voi][60ms] requires that segments that contrast for [voice] have voicing durations that are at least 60 ms apart.

- On the basis of the results of Experiment 1, I posit a family of *Periphery constraints that penalize forms that are too close to the periphery of the phonetic space. Like the MinDist constraints, *Periphery constraints refer directly to dimensions; thus, *Periphery[voi][5ms] is violated by any stop with less than 5 ms or more than 55 ms of voicing.

- Clements (2003) argues that languages tend to prefer inventories in which a relatively large number of segments is described by a relatively small number of features; he terms this tendency "feature economy". Although his proposal is focused on phonological features, he presents some evidence (325-326) that a similar principle of "gestural economy", which encourages reuse of a small number of articulatory gestures, operates independently. In a related vein, Ussishkin and Wedel (2003) argue that speakers of a given language have a repertoire of gestural "molecules" which shape the degree to which loanwords are modified to fit the phonotactics of the borrowing language.

  In the spirit of gestural economy, I posit a family of Match constraints that require two instances of the same segment in different contexts to have the same value along a given phonetic dimension (within some margin of error). For example, Match[voi][3ms] assigns one violation to every candidate in which there are two instances of the same segment (e.g., [p]) with voicing durations that are different by more than 3 ms.

- The analysis below also uses the IDENT constraints discussed in §5.1, which are evaluated in more or less the usual way. As in §5.1, I restrict these IDENT constraints to intervocalic segments. I also employ IDENT[–cont]/#___, a positional faithfulness constraint that applies only word-initially (Beckman 2004[1998]).

The tableau in (17) illustrates how this constraint set can derive intervocalic spirantization by imposing restrictions on the voicing dimension. The idealized inventories show the behavior of the full cross-classification of consonants for voicing (voiced vs. voiceless), continuancy (stop vs. spirant), and position (initial vs. intervocalic). I assume that by richness of the base, the input contains all eight possibilities.

The winning candidate, (d), has spirantization of voiced stops intervocalically. The fully faithful candidate (a) loses because it has four violations of *PERIPHERY[voi][5ms]: while (a) has four stops at the edges of the voicing space, (d) has only three, since [b] does not appear intervocalically on the surface. *PERIPHERY must outrank both IDENT[–cont] and *MERGE, or else (d) would lose, either because it changes the continuancy value of underlying intervocalic /b/ or because it eliminates the contrast between /aba/ and /aβa/.

(17)

	/pa/$_A$ /fa/$_C$ /apa/$_E$ /afa/$_G$	/ba/$_B$ /βa/$_D$ /aba/$_F$ /aβa/$_H$	MinDist[voi][60ms]	Ident[−cont]/#___	Match[voi][3ms]	*Periphery[voi][5ms]	Ident[−voi]	Ident[+voi]	Ident[−cont]	*Merge
a.	[p$_0$a] [fa] [ap$_0$a] [afa]	[b$_{60}$a] [βa] [ab$_{60}$a] [aβa]				****!				
b.	[p$_5$a] [fa] [ap$_5$a] [afa]	[b$_{55}$a] [βa] [ab$_{55}$a] [aβa]	**!							
c.	[p$_0$a] [fa] [ap$_0$a] [afa]	[βa]$_{B,D}$ [aβa]$_{F,H}$		*!		**			*	**
☞d.	[p$_0$a] [fa] [ap$_0$a] [afa]	[b$_{60}$a] [βa] [aβa]$_{F,H}$				***			*	*
e.	[p$_0$a] [fa] [ap$_5$a] [afa]	[b$_{60}$a] [βa] [aβa]$_{F,H}$			*!	**			*	*
f.	[p$_0$a] [fa] [ap$_0$a]$_{E,F}$ [afa]	[b$_{60}$a] [βa] [aβa]				***		*!		*
g.	[p$_0$a] [fa] [afa]	[b$_{60}$a] [βa] [ab$_0$a]$_{E,F}$ [aβa]				***	*!			*

Candidate (b) avoids violating *Periphery at all by moving all four stops slightly towards the center of the voicing space. This candidate thus incurs two violations of MinDist[voi][60ms]: both word-initially and intervocalically, the stops distinguished by voicing are too close together in the phonetic space. MinDist must therefore outrank *Periphery (which the winner (d) does violate) in addition to Ident[–cont] and *Merge. The failure of candidates (a) and (b) demonstrates the squeezing of the voicing dimension in this analysis: *Periphery requires more compression of the voicing dimension than MinDist will allow.

Candidate (c) avoids two of the four violations of *Periphery incurred by the fully faithful candidate by spirantizing all of its voiced stops; thus, only [p] remains to violate *Periphery. However, this candidate is eliminated by a fatal violation of Ident[–cont]/#___: positional faithfulness at the beginning of the word is more important than avoiding a word-initial [b] at the periphery of the voicing space. Ident[–cont]/#___ must outrank *Periphery. (Candidate (c) also does worse than (d) on *Merge; however, we know from candidates (a) and (b) that this constraint ranks *below* *Periphery. Thus, the fatal violation of (c) must come from Ident[–cont]/#___.)

An alternative way to eliminate candidate (c) would be to apply *Periphery only to intervocalic stops; in that case, candidates (c) and (d) would each violate *Periphery once, and the winner (d) would harmonically bound (c). The rationale for this restriction would be that Experiment 1, like Experiments 2 – 4, investigated only intervocalic segments; thus, the intervocalic environment is the only one for which we have evidence of the 'X-pattern'. However, there are hints that articulatory compression is not limited to the intervocalic environment; although final voicing was not systematically manipulated in Experiment 1, §3.3.3 notes that the 'X-pattern' seems to be present for the voicing of the [d] of *said* in the frame sentence as well. Thus, I apply *Periphery to all segments, regardless of environment; but restricting *Periphery would not affect the main point of the present analysis.

Candidate (e) attempts to satisfy both *Periphery and MinDist by spirantizing intervocalic /b/ and adding a small amount of voicing to intervocalic /p/: since intervocalic [b] no longer surfaces, [p] can move towards the middle of the voicing space without violating MinDist. However, with voicing added to intervocalic [p], the two [p]s in candidate (e) no longer have the same amount of voicing, thus violating Match[voi][3ms]. With Match ranked above *Periphery, candidate (e) loses.

Note that without Match, candidate (e) would harmonically bound candidate (d): the two candidates perform identically on all other constraints except *Periphery, where (e) does better. Indeed, if we assume that there is a whole family of *Periphery constraints requiring various distances from the edge of the voicing space, then both candidates would be harmonically bounded by one in which intervocalic [p] has 20 ms of voicing (the closest a voiceless stop can come to the middle of the voicing space without becoming a voiced stop). It is entirely possible that some languages have a 'pull-chain' pattern of this type, whereby intervocalic spirantization of voiced stops enables greater voicing in intervocalic voiceless stops. (Indeed, if a voiceless stop with extra voicing is transcribed in written descriptions as a voiced stop, then perhaps some patterns with both voicing and spirantization intervocalically should be analyzed in exactly this way.) However, in the absence of sufficient data, I do not want to make the strong prediction that *every* language with intervocalic spirantization of voiced stops also has some intervocalic voicing. The Match constraint, highly ranked, allows candidate (d) to surface.

Like (d), candidate (f) attempts to resolve the conflict between MinDist and *Periphery by neutralizing intervocalic /b/ with something else. Where (d) employs spirantization, (f) employs devoicing. The two candidates have the same violation profiles, except that (d) violates Ident[–cont] where (f) violates Ident[+voi]. The universal ranking Ident[+voi] ≫ Ident[–cont] established by the results of Experiment 2 renders candidate (f) unable to win under any ranking.

Finally, candidate (g) neutralizes /apa/ and /aba/ by voicing /p/ rather than by devoicing /b/. Here, the fatal violation is assigned by Ident[–voi]. If we assume that Ident[–voi] and Ident[–cont] are freely rankable (unlike Ident[+voi] and Ident[–cont]), then we can reverse this ranking to allow (g), an attested pattern, to surface. The abbreviated tableau in (18) illustrates.

(18)

			MinDist[voi][60ms]	*Periphery[voi][5ms]	Ident[+voi]	Ident[−cont]	Ident[−voi]	*Merge
	/pa/$_A$ /fa/$_C$ /apa/$_E$ /afa/$_G$	/ba/$_B$ /βa/$_D$ /aba/$_F$ /aβa/$_H$						
a.	[p$_0$a] [fa] [ap$_0$a] [afa]	[b$_{60}$a] [βa] [ab$_{60}$a] [aβa]		****!				
b.	[p$_5$a] [fa] [ap$_5$a] [afa]	[b$_{55}$a] [βa] [ab$_{55}$a] [aβa]	**!					
c.	[p$_0$a] [fa] [ap$_0$a] [afa]	[b$_{60}$a] [βa] [aβa]$_{F,H}$		***		*!		*
d.	[p$_0$a] [fa] [ap$_0$a]$_{E,F}$ [afa]	[b$_{60}$a] [βa] [aβa]		***	*!			*
☞ e.	[p$_0$a] [fa] [afa]	[b$_{60}$a] [βa] [ab$_0$a]$_{E,F}$ [aβa]		***			*	*

Thus, squeezing the voicing dimension with MinDist and *Periphery constraints can have at least two different results, depending on the ranking of other constraints: one member of the voicing opposition can move along a perpendicular dimension by spirantizing (illustrated in (17)), or the voicing distinction itself can be eliminated (illustrated in (18)). Squeezing the continuancy dimension has analogous effects: either one member of the contrast changes on a perpendicular dimension (voicing), or the continuancy distinction is collapsed through spirantization. These possibilities are illustrated in the tableaux in (19) and (20), respectively. In these tableaux, the MinDist and *Periphery constraints evaluate only voiceless segments. Since the best measure or combination of measures for continuancy is not obvious, I leave the relevant phonetic dimension for these constraints unspecified. For the sake of discussion, I assume a phonetic space similar to that used for voicing above: a range from 0 (stops) to 60 (spirants).

(19)

	/pa/$_A$ /fa/$_C$ /apa/$_E$ /afa/$_G$	/ba/$_B$ /βa/$_D$ /aba/$_F$ /aβa/$_H$	MinDist[cont][60]	*Periphery[cont][5]	Ident[−cont]	Ident[−voi]	*Merge
a.	[p$_0$a] [f$_{60}$a] [ap$_0$a] [af$_{60}$a]	[ba] [βa] [aba] [aβa]		****!			
b.	[p$_5$a] [f$_{55}$a] [ap$_5$a] [af$_{55}$a]	[ba] [βa] [aba] [aβa]	**!				
☞ c.	[p$_0$a] [f$_{60}$a] [af$_{60}$a]	[ba] [βa] [aba]$_{E,F}$ [aβa]		***		*	*
d.	[p$_0$a] [f$_{60}$a] [af$_{60}$a]$_{E,G}$	[ba] [βa] [aba] [aβa]		***	*!		*

(20)

			MinDist[cont][60]	*Periphery[cont][5]	Ident[−voi]	Ident[−cont]	*Merge
	/pa/$_A$ /fa/$_C$ /apa/$_E$ /afa/$_G$	/ba/$_B$ /βa/$_D$ /aba/$_F$ /aβa/$_H$					
a.	[p$_0$a] [f$_{60}$a] [ap$_0$a] [af$_{60}$a]	[ba] [βa] [aba] [aβa]		****!			
b.	[p$_5$a] [f$_{55}$a] [ap$_5$a] [af$_{55}$a]	[ba] [βa] [aba] [aβa]	**!				
c.	[p$_0$a] [f$_{60}$a] [af$_{60}$a]	[ba] [βa] [aba]$_{E,F}$ [aβa]		***	*!		*
☞d.	[p$_0$a] [f$_{60}$a] [af$_{60}$a]$_{E,G}$	[ba] [βa] [aba] [aβa]		***		*	*

With MinDist and *Periphery constraints that apply to voiced segments, we can obtain spirantization of intervocalic /b/ in exactly the same way as in (20). However, we cannot cause /b/ to devoice by squeezing the continuancy dimension in the same way as in (19) since Ident[+voi] always outranks Ident[–cont].

Thus, given this set of constraints motivated by the results of Experiments 1 – 4, it is possible to generate both intervocalic voicing and intervocalic spirantization. This analysis demonstrates that an account of these lenition processes does not depend on the existence of a constraint that simply favors the lenited forms over the unlenited forms – exactly the kind of constraint for which Experiment 1 failed to find evidence. In addition, the fixed ranking of IDENT[+voi] over IDENT[–cont] motived by Experiment 2 correctly rules out the unattested pattern of intervocalic devoicing.

5.3.2 Intervocalic Despirantization?

Although the constraint set described in the previous section correctly generates several attested lenition patterns while ruling out intervocalic devoicing, there is another unattested pattern that *is* predicted to occur: intervocalic despirantization. If MINDIST and *PERIPHERY constraints restrict the continuancy dimension and the lowest-ranked IDENT constraint is IDENT[+cont] (a constraint not considered in the tableaux above), the pattern that emerges as the winner is one in which intervocalic spirants become stops.

(21)

			MinDist[cont][60]	*Periphery[cont][5]	Ident[−voi]	Ident[−cont]	Ident[+cont]	*Merge
	/pa/$_A$ /fa/$_C$ /apa/$_E$ /afa/$_G$	/ba/$_B$ /βa/$_D$ /aba/$_F$ /aβa/$_H$						
a.	[p$_0$a] [f$_{60}$a] [ap$_0$a] [af$_{60}$a]	[ba] [βa] [aba] [aβa]		****!				
b.	[p$_5$a] [f$_{55}$a] [ap$_5$a] [af$_{55}$a]	[ba] [βa] [aba] [aβa]	**!					
c.	[p$_0$a] [f$_{60}$a] [af$_{60}$a]	[ba] [βa] [aba]$_{E,F}$ [aβa]		***	*!			*
d.	[p$_0$a] [f$_{60}$a] [af$_{60}$a]$_{E,G}$	[ba] [βa] [aba] [aβa]		***		*!		*
☞ e.	[p$_0$a] [f$_{60}$a] [ap$_0$a]$_{E,G}$	[ba] [βa] [aba] [aβa]		***			*	*

The problem is that the constraints that force lenition, MinDist and *Periphery, are non-directional. MinDist does not care where contrasting elements are located on the relevant scale, as long as they are far enough apart. If there is only one element on the scale, there is no contrast and MinDist has nothing to say at all. *Periphery forbids segments from being too close to the edge of the scale, but it does not favor one end of the scale over another. A stop with no voicing at all is just as bad as a stop with the maximum amount of voicing. Lenition, by contrast, is directional. Intervocalic voiceless stops may become voiced, but not the reverse; stops may become spirants, but not the reverse.

I have argued that we can solve the problem of directionality in the case of voicing by considering a range of possible alternations for underlying voiced stops. Spirantization is such a perceptually 'good' (that is, non-salient) alternation for voiced stops that devoicing never occurs: if a voiced stop alternates at all, there is always a better option than devoicing. The directionality of voicing alternations emerges from restrictions on how one member of the voicing contrast can alternate, not from an asymmetry along the voicing dimension itself.

Is a similar solution possible for the case of (de)spirantization? In principle, yes. We could hypothesize, for example, that spirants never become stops intervocalically because they could undergo an even less perceptible change by becoming approximants. If experimental data supported this proposal, we could posit a universal ranking $\textsc{Ident}[-\text{son}] \gg \textsc{Ident}[+\text{cont}]$ and rule out intervocalic despirantization.

Unfortunately, this explanation reveals an inherent weakness of the approach of the P-map for a series of unidirectional alternations such as lenition processes, as illustrated in figure 5.2. The P-map by itself does not provide the needed directionality: for each segment along the chain, it rules out the possibility of moving to the left by appealing to the superior perceptual consequences of moving to the right instead. Once we reach the rightmost element in the chain, this line of argumentation is no longer possible; and if we simply add another element ot the chain, the problem has only been pushed back a step. If it is the case (and I know of no counterexamples) that spirants may lenite to approximants intervocalically

Figure 5.2: Series of unidirectional leniting intervocalic alternations

$$\mathrm{p} \longrightarrow \mathrm{b} \longrightarrow \beta \longrightarrow \mathrm{w}$$

but approximants do not become spirants, then we have solved the problem for spirants only to create another problem for approximants. It's turtles all the way down.

It is at this point that articulatory considerations are usually brought in to play. Rather than assuming a complex set of perceptual differences that results in a chain of unidirectional alternations, it seems much simpler to suppose that articulatory effort reduction favors some sounds over others, thus encouraging change in only one direction. However, the results of Experiment 1 do not support such a proposal: there is no evidence that subjects in the intoxicated condition were more likely to lenite than subjects in the sober condition. It is certainly possible that further experimental work could produce evidence in support of an articulatory basis for the directionality of lenition, but that is not the data we have at hand.

I do not offer a solution here to the problem of directionality in lenition. The contribution of Experiments 1 – 4 is the observation that phonetic facts may motivate a substantial part of the typology of lenition, but not in the way that is usually assumed. A tendency to reduce articulatory effort may provide the precursors for lenition, but by compressing the articulatory space on both ends, rather than by causing an overall shift in the direction of lenited forms as generally believed. In addition, perceptual facts, long neglected in the study of lenition, can contribute to our understanding of why the alternations involved in lenition only go in one direction, even if perception does not ultimately tell the whole story.

5.4 Conclusion

This chapter has illustrated the implications of Experiments 1 – 4 for any phonological analysis that takes phonetic facts seriously. First, the results of Experiments 2 and 4, when combined with the P-map, provide a very good match to the broad typological facts: although voiceless stops may voice or spirantize intervocalically, voiced stops may spirantize but may not devoice. However, applying the same procedure to the results of Experiment 3 yields incorrect predictions regarding which voiced stops should be more likely to spirantize. This result demonstrates that not every difference in perceptibility should be projected by the P-map into a universal ranking of faithfulness constraints; I have suggested some ways in which we might constrain the P-map in a principled manner.

Second, the results of Experiment 1 do not support the traditional account of lenition as effort reduction; that is, Experiment 1 provides no evidence that reducing articulatory effort makes subjects more likely to produce lenited forms. Rather, the compressed articulatory space exhibited by subjects in the intoxicated condition is reminiscent of approaches that penalize productions in the periphery of the phonetic space, notably Dispersion Theory.

I have also shown that a Dispersion-Theoretic analysis is capable of modeling intervocalic lenition even without a constraint that favors lenited forms over unlenited ones outright. This analysis illustrates the kind of approach phonology must take in order to account for lenition in a way consistent with the results of Experiment 1 – 4. Although some questions remain (such as the best way to rule out intervocalic despirantization), I submit that this approach is a step in the right direction because it adheres more closely to the phonetic facts of lenition than do previous approaches.

Chapter 6

Conclusion

There is nearly universal agreement that intervocalic lenition is driven, at least in part, by phonetic factors. However, there is less agreement on what exactly the relevant factors are. A widely accepted view is that lenited forms require less effort to produce than unlenited forms, but researchers do not agree on what makes one form more difficult than another, or on the degree to which a given measure of difficulty is actually relevant to lenition. In this dissertation, I have argued that the articulatory understanding of lenition must be revised in two substantial ways.

First, Experiment 1 failed to find evidence that lenited forms are easier to produce than unlenited forms. This experiment involved a novel approach to investigating articulatory effort: I attempted to observe effort reduction in action by comparing the speech of intoxicated subjects (hypothesized to use less articulatory effort) with that of sober subjects. Although the speech of the two groups did differ, it was not the case that intoxicated subjects were more likely to produce lenited forms; rather, intoxicated subjects exhibited an overall contraction of the articulatory space. Thus, the relationship between lenition and articulatory effort reduction appears to be more complicated than commonly assumed.

Second, perceptual facts – long overlooked in the study of the phonetic basis of lenition – can help us understand in some cases why lenition is unidirectional. The change /D/ $\rightarrow$ [Z] intervocalically is more difficult to perceive than the change /D/ $\rightarrow$ [T], while the changes /T/ $\rightarrow$ [S] and /T/ $\rightarrow$ [D] are about equally perceptible. Combined with a framework such as the P-map that posits that more salient changes to underlying forms are less likely than less salient changes, these facts provide us with an explanation for the fact that lenition of voiceless stops may involve changes to either voicing or continuancy, while lenition of voiced stops may change continuancy but not voicing.

These two results suggest that we can no longer do 'phonology as usual' when analyzing lenition. Chapter 5 illustrated what a phonological analysis would have to look like in order to be consistent with the results of Experiments 1 – 4. The analysis presented there shows that it is possible to describe lenition patterns in the context of Optimality Theory even without a constraint that favors lenited forms over unlenited forms outright.

I conclude that phonetic factors are relevant to intervocalic lenition, but not in the way they are usually thought to be. More broadly, this work illustrates the value of broadening the range of phonetic sources we are willing to consider for a given phonological phenomenon, and of applying a variety of experimental paradigms to difficult empirical problems.

Chapter 7

Appendices

7.1 Classification of Languages in the Database of Gurevich (2004)

The following table lists how each language in the database of Gurevich (2004) is classified along the parameters relevant to the discussion in §2. A total of 16 languages were excluded because segment inventories were not provided in the database: Cuna; British English; Cockney English; Liverpool English; London, Leeds, & Fife English; New Zealand English; Haitian Creole; Icelandic; Southern Italian; Middle Chinese; Northern Corsican; Numic; Proto-Germanic; Mexico City Spanish; Tigrinya; Yuman.

Each language is classified for each place of articulation at which the language has either a voiceless stop or a voiced stop. In the broader groupings above, 'labials' include labials; 'coronals' include dentals, alveolars, and retroflexes; and 'dorsals' include velars. 'Labio-X' and 'palato-X' are classified in the same way as

‘X’.

In the field ‘Lenition of T’, I indicate what (if any) lenition processes applies to the relevant voiceless stop. The possibilities are ‘voicing’, ‘spirantization’, ‘both’, and ‘other’. ‘NA’ indicates that the language lacks a voiceless stop at the relevant place of articulation.

In the field ‘Spirantization of D’, I indicate whether the relevant voiced stop spirantizes or not. If spirantization is rare, this is so indicated in the table, and the language is considered to spirantize that stop for the purposes of the typology above. If voiced stops flap, this is also indicated. This information is included because in some languages (such as Malayalam), there is spirantization of voiced stops at most places of articulation, but some coronals undergo flapping instead of spirantization. These coronals are considered to not undergo spirantization for the purposes of the classification above, except in one case. In Senoufo, there is also intervocalic voicing of voiced stops; here, flapping clearly allows the language to avoid neutralization of /t/ and /d/. Thus, Senoufo coronals are counted as spirantizing in the table that lists spirantizing languages by whether or not they also have intervocalic voicing (but not in the other tables). Again, ‘NA’ indicates that the language lacks the relevant voiced stop.

In the field ‘Presence of Z’, I indicate whether the relevant voiced spirant is phonemically present in the language or not. A second entry in parentheses accompanies some places of articulation; these entries contain information on voiced spirants that are not usually the result of spirantization but are sufficiently similar to warrant investigation. For labials, the ‘extra’ spirant is [v]; for alveolars, it is [z]; for palatals, it is [ʒ] (as opposed to [ʝ], the true palatal fricative).

Language	POA	Len. of T	Len. of D	Presence of Z
Amele (Haia)	labial	spir.	none	no (no)
	alveolar	none	none	no (no)
	velar	NA	none	no
	labiovelar	none	none	no
Ancient Greek	labial	spir.	none	no (no)
	alveolar	spir.	none	no (no)
	velar	spir.	none	no
Ao (Chungli)	labial	voicing	NA	no (no)
	alveolar	voicing	NA	no (yes)
	palatal	none	NA	no
	velar	voicing	NA	no
Apalai	labial	none	NA	no (no)
	alveolar	none	NA	no (yes)
	velar	voicing	NA	no
Apatani	labial	none	spir.	no (no)
	alveolar	none	none	no (no)
	velar	none	none	no
Arabic (Egyptian)	labial	NA	none	no (no)
	alveolar	none	none	no (yes)
	velar	none	none	no
	uvular	none	NA	yes
Arabic (Saʕi:di Egyptian)	labial	NA	none	no (no)
	alveolar	none	none	no (yes)
	velar	none	none	no
Arbore	labial	none	none	no (no)
	alveolar	none	none	no (yes)
	velar	none	none	no
Assamese	labial	spir.	spir.	no (no)
	alveolar	spir.	none	no (yes)
	velar	none	none	no
Babine	labial	NA	none	no (no)
	alveolar	none	none	no (yes)
	velar	none	none	yes
	uvular	none	none	yes
	labiouvular	none	none	yes
Badimaya	labial	none	NA	no (no)
	dental	both	NA	no
	alveolar	none	NA	no (no)
	retroflex	none	NA	no

Language	POA	Len. of T	Len. of D	Presence of Z
	palatal	both	NA	no (no)
	velar	none	NA	no
Balti (Purki)	labial	none	none	no (no)
	dental	none	spir.	no
	alveolar	none	none	no (yes)
	velar	none	none	no
	uvular	none	NA	yes
Bashkir	labial	none	spir.	no (yes)
	alveolar	none	none	yes (yes)
	velar	none	none	no
	uvular	none	NA	yes
Basque (Souletin)	labial	none	spir.	no (no)
	alveolar	none	spir.	no (yes)
	palatal	none	spir.	yes (yes)
	velar	none	spir.	no
Blackfoot	labial	none	NA	no (no)
	alveolar	none	NA	no (no)
	velar	none	NA	no
Bontoc	labial	none	none	no (no)
	alveolar	none	none	no (no)
	velar	none	none	no
	uvular	none	NA	no
Bulgarian	labial	none	none	no (yes)
	alveolar	none	none	no (yes)
	palatal	none	none	no (yes)
	velar	none	NA	no
Canela-Krahô	labial	voicing	NA	no (no)
	alveolar	voicing	NA	no (no)
	velar	voicing	NA	no
Car Nicobarese	labial	none	NA	no (no)
	alveolar	none	none	no (no)
	retroflex	none	NA	no
	velar	none	NA	no
Catalan (Eastern)	labial	none	spir.	no (no)
	alveolar	none	spir.	no (yes)
	velar	none	spir.	no
Dahalo	labial	none	spir.	no (yes)
	dental	none	none	no
	alveolar	none	spir.	no (no)

Language	POA	Len. of T	Len. of D	Presence of Z
	velar	none	none	no
	labiovelar	none	none	no
Djabugay	labial	voicing	NA	no (no)
	alveolar	voicing	NA	no (no)
	palatal	voicing	NA	no (no)
	velar	voicing	NA	no
Efik (Calabar-Creek)	labial	NA	spir.	no (no)
	alveolar	none	flapping	no (no)
	velar	both	NA	no
	labiovelar	none	NA	no
English (American)	labial	none	none	no (yes)
	alveolar	other	flapping	yes (yes)
	velar	none	none	no
English (Cardiff)	labial	none	spir.	no (yes)
	alveolar	none	none	yes (yes)
	velar	none	none	no
Estonian (Southern)	labial	voicing	NA	no (no)
	dental	voicing	NA	no
	alveolar	voicing	NA	no (no)
	velar	voicing	NA	no
Faroese	labial	voicing	NA	no (yes)
	alveolar	voicing	NA	no (no)
	palatal	voicing	NA	no (no)
	velar	voicing	NA	no
Finnish	labial	none	none	no (no)
	alveolar	none	none	no (no)
	velar	none	none	no
French (Périgourdin)	labial	none	none	no (yes)
	alveolar	voicing	spir.	no (yes)
	velar	none	none	no
Gbɛya	labial	none	none	no (yes)
	alveolar	none	none	no (yes)
	velar	none	none	no
	labiovelar	none	none	no
Georgian	labial	none	none	no (yes)
	alveolar	none	none	no (yes)
	palatal	none	none	no (yes)
	velar	none	none	no
	uvular	none	NA	yes

Language	POA	Len. of T	Len. of D	Presence of Z
Gitksan	labial	voicing	NA	no (no)
	alveolar	voicing	NA	no (no)
	velar	voicing	NA	no
	labiovelar	voicing	NA	no
	uvular	voicing	NA	no
Gojri	labial	none	other	no (no)
	alveolar	none	other	no (yes)
	retroflex	none	other	no
	palatal	none	other	no (no)
	velar	none	other	yes
	uvular	none	NA	no
Gooniyandi	labial	voicing	NA	no (no)
	dental	voicing	NA	no
	alveolar	voicing	NA	no (no)
	retroflex	voicing	NA	no
	palatal	voicing	NA	no (no)
	velar	voicing	NA	no
Gothic	labial	none	spir.	no (no)
	alveolar	none	spir.	no (yes)
	velar	none	spir.	no
Greenlandic (West)	labial	none	NA	no (yes)
	alveolar	none	NA	no (no)
	palatal	NA	none	no (no)
	velar	none	none	no
	uvular	spir./both	NA	no
Guayabero	labial	none	none	yes (no)
	alveolar	none	none	no (no)
	velar	none	NA	no
Gujarati	labial	none	spir.	no (no)
	alveolar	none	spir.	no (yes)
	retroflex	none	spir.	no
	velar	none	spir.	no
Hebrew (Tiberian)	labial	spir.	spir.	no (no)
	alveolar	spir.	spir.	no (yes)
	velar	spir.	spir.	no
	uvular	none	NA	no
Kabardian (Terek)	labial	none	none	no (yes)
	alveolar	none	none	no (yes)
	palatal	none	none	yes (yes)

Language	POA	Len. of T	Len. of D	Presence of Z
	labiovelar	none	none	no
	uvular	none	NA	yes
	labiouvular	none	NA	yes
Kagate	labial	none	spir.	no (no)
	alveolar	none	none	no (no)
	retroflex	none	none	no
	velar	none	other	no
Kaliai-Kove (Kandoka-Lusi)	labial	none	NA	yes (no)
	alveolar	none	NA	no (no)
	velar	none	spir.	no
Kanakuru	labial	other	none	no (no)
	alveolar	other	none	no (no)
	labioalveolar	none	none	no
	palatal	NA	none	no (no)
	velar	other	none	no
	labiovelar	none	none	no
Kannada	labial	voicing	NA	no (no)
	alveolar	voicing	NA	no (no)
	retroflex	none	NA	no
	velar	voicing	NA	no
Kanuri	labial	none	spir.	no (no)
	alveolar	none	none	no (yes)
	velar	none	spir.	no
Karao	labial	spir.	none	no (no)
	alveolar	spir.	other	no (no)
	velar	none	none	no
	labiovelar	NA	other	no
	uvular	spir.	NA	no
Kashmiri	labial	none	none	no (no)
	alveolar	none	none	no (yes)
	retroflex	none	flapping	no
	velar	none	none	no
Kirghiz	labial	none	none	yes (no)
	alveolar	none	none	no (yes)
	velar	none	none	no
Korean	labial	voicing	NA	no (no)
	alveolar	voicing	NA	no (no)
	velar	voicing	NA	no
Kuna (Paya)	labial	none	spir.	no (no)

Language	POA	Len. of T	Len. of D	Presence of Z
	alveolar	none	spir.	no (yes)
	labioalveolar	none	none	no
	velar	none	spir.	no
	labiovelar	none	none	no
Kupia (Sujanakota)	labial	spir.	none	no (no)
	alveolar	none	none	no (no)
	retroflex	other	flapping	no
	velar	none	none	no
Ladakhi (Central)	labial	none	spir.	no (no)
	alveolar	none	spir.	no (yes)
	retroflex	none	none	no
	velar	none	spir.	no
Lahaul (Pattani)	labial	none	none	no (no)
	alveolar	none	none	no (yes)
	retroflex	none	flapping	no
	palatal	none	none	no (no)
	velar	none	none	no
Lama	labial	other	NA	no (no)
	alveolar	none	NA	no (no)
	palatal	none	NA	no (no)
	velar	none	NA	no
	labiovelar	none	NA	no
Lamani	labial	none	none	no (no)
	alveolar	none	none	no (no)
	retroflex	none	flapping	no
	velar	none	none	no
Laotian (Vientiane)	labial	none	none	no (no)
	alveolar	none	none	no (no)
	palatal	none	NA	no (no)
	velar	none	NA	no
	labiovelar	none	NA	no
Lezgian	labial	voicing	none	no (no)
	alveolar	voicing	none	no (yes)
	labioalveolar	voicing	NA	no (yes)
	velar	voicing	none	no
	labiovelar	voicing	none	no
	uvular	both	NA	yes
	labiouvular	both	NA	yes
Limbu	labial	voicing	other	no (no)

Language	POA	Len. of T	Len. of D	Presence of Z
(Phedāppe)	alveolar	voicing	NA	no (no)
	velar	voicing	NA	no
Lotha	labial	none	NA	no (yes)
	alveolar	voicing	NA	no (yes)
	velar	voicing	NA	no
Lowland Murut (Timugon)	labial	none	spir.	no (no)
	alveolar	none	flapping	no (no)
	velar	none	spir.	no
Macushi	labial	voicing	NA	no (no)
	alveolar	voicing	NA	no (no)
	velar	voicing	NA	no
Maidu	labial	other	none	no (no)
	alveolar	other	none	no (no)
	velar	other	NA	no
Malayalam	labial	voicing	spir.	no (no)
	dental	voicing	spir.	no
	retroflex	voicing	flapping	no
	velar	voicing	spir.	no
Manobo (Ata)	labial	none	spir.	no (no)
	alveolar	none	spir.	no (no)
	velar	none	spir.	no
	uvular	none	NA	no
Maori	labial	none	NA	no (no)
	alveolar	none	NA	no (no)
	velar	spir.	NA	no
Marathi (Halabi)	labial	none	none	no (no)
	alveolar	none	none	no (no)
	retroflex	none	flapping	no
	palatal	none	none	no (no)
	velar	none	none	no
Mataco (Noctenes)	labial	none	NA	no (no)
	alveolar	none	NA	no (no)
	labiovelar	none	NA	no
	uvular	none	NA	no
Maxakalí	labial	other	NA	no (no)
	alveolar	other	NA	no (no)
	palatal	other	NA	no (no)
	velar	other	NA	no
Mbabaram	labial	voicing	NA	no (no)

Language	POA	Len. of T	Len. of D	Presence of Z
	dental	voicing	NA	no
	alveolar	voicing	NA	no (no)
	labioalveolar	voicing	NA	no
	palatal	voicing	NA	no (no)
	velar	voicing	NA	no
Modern Irish	labial	none	none	no (no)
	alveolar	none	none	no (no)
	velar	none	none	no
Moghamo (Batibo)	labial	none	none	no (no)
	alveolar	none	flapping	no (no)
	velar	none	spir.	no
Mohawk (Akwesasne)	alveolar	voicing	NA	no (no)
	velar	voicing	NA	no
Mongolian (Kalkha)	labial	none	spir.	no (no)
	alveolar	none	none	no (no)
	velar	none	spir.	no
Navajo	labial	NA	none	no (no)
	alveolar	none	none	no (yes)
	velar	none	none	yes
Nepali	labial	spir.	spir.	no (no)
	alveolar	none	other	no (no)
	retroflex	none	flapping	no
	velar	spir.	other	no
Newari	labial	none	none	no (no)
	alveolar	none	none	no (no)
	velar	none	none	no
Nez Perce	labial	none	NA	no (no)
	dental	none	NA	no
	alveolar	spir.	NA	no (no)
	velar	spir.	NA	no
	uvular	spir.	NA	no
Nkore-Kiga	labial	none	spir.	no (yes)
	alveolar	NA	none	no (yes)
	velar	none	none	no
Nyawaygi	labial	NA	none	no (no)
	alveolar	NA	none	no (no)
	palatal	NA	none	no (no)
	velar	NA	none	no
Páez	labial	none	none	yes (no)

Language	POA	Len. of T	Len. of D	Presence of Z
	alveolar	none	none	no (yes)
	palatoalveolar	none	none	no (no)
	velar	none	none	yes
Panyjima (Mijaranypa)	labial	none	NA	no (no)
	dental	none	NA	no
	alveolar	none	NA	no (no)
	retroflex	other	NA	no
	palatal	none	none	no (no)
	velar	none	NA	no
Pawnee (South Bend & Skiri)	labial	none	NA	no (no)
	alveolar	none	NA	no (no)
	velar	none	NA	no
Pipil (Cuisnahuat)	labial	none	none	no (no)
	alveolar	none	none	no (no)
	velar	none	none	no
Proto-Ainu	labial	none	NA	no (no)
	alveolar	none	none	no (no)
	velar	none	other	no
	uvular	none	NA	no
Proto-Bantu	labial	none	spir.	no (no)
	alveolar	none	other	no (yes)
	velar	none	spir.	no
Ptolemaic Greek	labial	none	none	no (no)
	alveolar	none	none	no (yes)
	velar	none	spir.	no
Punjabi	labial	spir.	none	no (no)
	alveolar	none	none	no (yes)
	retroflex	none	none	no
	palatal	none	none	no (no)
	velar	none	none	no
Purki	labial	none	none	no (no)
	dental	none	spir.	no
	alveolar	none	flapping	no (yes)
	velar	none	none	no
	uvular	none	NA	yes
Quechua	labial	none	NA	no (no)
	alveolar	none	NA	no (no)
	velar	spir.	NA	no
	uvular	spir.	NA	no

Language	POA	Len. of T	Len. of D	Presence of Z
Russian	labial	none	other	no (yes)
	alveolar	none	other	no (yes)
	velar	none	other	no
Saek	labial	none	none	no (no)
	alveolar	none	none	no (no)
	palatal	none	NA	no (no)
	velar	none	NA	yes
Sanuma	labial	voicing	NA	no (no)
	alveolar	voicing	NA	no (no)
	velar	voicing	NA	no
Sawai	labial	none	none	no (no)
	alveolar	none	flapping	no (no)
	velar	none	none	no
Sekani	labial	none	NA	no (no)
	alveolar	none	NA	no (yes)
	velar	none	NA	yes
Senoufo	labial	voicing	spir.	no (yes)
	alveolar	voicing	flapping	no (yes)
	velar	voicing	spir.	no
	labiovelar	none	none	no
Serbo-Croatian	labial	none	none	no (yes)
	alveolar	none	none	no (yes)
	palatoalveolar	none	none	no
	velar	none	none	no
Shapsug (Düzce)	labial	none	none	no (no)
	dental	none	none	no
	alveolar	none	none	no (yes)
	palatal	none	none	yes (yes)
	velar	none	none	yes
	labiovelar	none	none	no
	uvular	none	NA	yes
	labiouvular	none	NA	yes
Shina	labial	none	spir.	no (yes)
	alveolar	none	spir.	no (yes)
	retroflex	none	flapping	yes
	velar	none	spir.	yes
Shoshone (Tümpisa)	labial	spir./both	NA	no (no)
	alveolar	spir./both	NA	no (no)
	palatal	spir./both	NA	no (no)

Language	POA	Len. of T	Len. of D	Presence of Z
	velar	spir./both	NA	no
	labiovelar	spir./both	NA	no
Somali	labial	NA	spir.	no (no)
	alveolar	none	spir.	no (no)
	retroflex	NA	flapping	no
	velar	none	spir.	no
	uvular	none	NA	no
Sotho (Southern)	labial	none	spir.	no (yes)
	alveolar	none	none	no (no)
	velar	none	NA	no
Southern Tati (Chali)	labial	none	none	no (yes)
	alveolar	none	none	no (yes)
	velar	none	none	no
	uvular	both	NA	no
Southern Tati (Eshtehardi)	labial	none	none	no (yes)
	alveolar	none	none	no (yes)
	velar	none	none	no
	uvular	none	NA	no
Southern Tati (Takestani)	labial	none	none	no (yes)
	alveolar	none	none	no (yes)
	velar	none	spir.	no
	uvular	none	NA	no
Southern Tati (Xiaraji)	labial	none	none	no (yes)
	alveolar	none	none	no (yes)
	velar	none	none	no
	uvular	none	NA	no
Spanish (Andalusian)	labial	none	spir.	no (no)
	alveolar	none	spir.	no (no)
	velar	none	spir.	no
Tahltan (Iskut)	labial	NA	none	no (no)
	dental	voicing	none	no
	alveolar	voicing	none	yes (yes)
	retroflex	voicing	none	no
	palatal	voicing	none	yes (no)
	velar	voicing	none	yes
	labiovelar	voicing	none	no
	uvular	voicing	none	yes
Taiwanese	labial	both	none	no (no)
	alveolar	other	NA	no (no)

Language	POA	Len. of T	Len. of D	Presence of Z
	velar	both	none	no
Tamazight Berber (Ayt Ayache)	labial	NA	spir.	no (no)
	alveolar	none	none	no (yes)
	velar	spir.	spir.	no
	uvular	none	NA	yes
Tamazight Berber (Ayt Ndhir)	uvular	none	NA	yes
Tamazight Berber (Ayt Seghrouchen)	labial	NA	spir.	no (no)
	alveolar	none	none	no (yes)
	velar	none	none	no
	uvular	none	NA	yes
Tamil	labial	both	none	no (yes)
	alveolar	both	none	no (no)
	retroflex	other	none	no
	velar	both	none	no
Tatar	labial	none	spir.	no (yes)
	alveolar	none	spir.	no (yes)
	velar	none	spir.	no
Tauya	labial	none	none	no (no)
	alveolar	none	NA	no (no)
	velar	other	none	no
Thai	labial	none	none	no (no)
	alveolar	none	none	no (no)
	palatal	none	NA	no (no)
	velar	none	none	no
Tharu (Chitwan)	labial	spir.	spir.	no (no)
	alveolar	none	none	no (no)
	retroflex	none	flapping	no
	velar	none	none	no
Toba Batak	labial	other	none	no (no)
	alveolar	other	none	no (no)
	velar	other	none	no
Tojolabal	labial	none	none	no (no)
	alveolar	none	none	no (no)
	palatal	none	NA	no (no)
	velar	none	spir.	no
Totonac (Misantla)	labial	voicing	NA	no (no)
	alveolar	voicing	NA	no (no)

Language	POA	Len. of T	Len. of D	Presence of Z
	velar	voicing	NA	no
	uvular	voicing/spir.	NA	no
Tsou (Tfuya)	labial	none	NA	no (yes)
	alveolar	none	NA	no (yes)
	velar	none	NA	no
Turkana	labial	none	none	no (no)
	alveolar	spir.	none	no (no)
	palatal	none	none	no (no)
	velar	none	none	no
Turkish	labial	none	none	yes (yes)
	alveolar	none	none	no (yes)
	velar	none	spir.	no
Tzeltal	labial	none	spir.	no (no)
	alveolar	none	spir.	no (no)
	velar	none	spir.	no
Uradhi	labial	both	NA	yes (no)
	dental	none	NA	no
	alveolar	both	NA	yes (no)
	palatal	none	NA	no (no)
	velar	both	NA	yes
Urdu	labial	none	none	no (yes)
	alveolar	none	none	no (yes)
	retroflex	none	flapping	no
	palatal	none	none	no (yes)
	velar	none	none	yes
	uvular	none	NA	no
Urubu-Kaapor	labial	voicing	NA	no (no)
	alveolar	voicing	NA	no (no)
	velar	voicing/both	NA	no
	labiovelar	none	NA	no
Uyghur	labial	none	spir.	no (yes)
	alveolar	none	none	no (yes)
	velar	spir.	spir.	no
	uvular	spir.	spir.	no
Uzbek	labial	spir.	other	no (no)
	alveolar	none	none	no (yes)
	velar	none	none	yes
	uvular	spir./both	NA	no
Vietnamese	labial	NA	none	no (yes)

Language	POA	Len. of T	Len. of D	Presence of Z
(Vinh)	alveolar	none	none	no (yes)
	palatal	none	NA	no (no)
	velar	none	NA	yes
Warndarang	labial	voicing	NA	no (no)
	dental	none	NA	no
	alveolar	voicing	NA	no (no)
	retroflex	voicing	NA	no
	palatal	voicing	NA	no (no)
	velar	voicing	NA	no
West Tarangan	labial	NA	none	no (no)
	alveolar	none	none	no (no)
	velar	other	NA	no
Wiyot	labial	none	none	no (no)
	alveolar	none	NA	no (no)
	velar	none	none	no
Yakut	labial	voicing	none	no (no)
	alveolar	none	none	no (no)
	velar	spir.	none	no
Yana	labial	voicing	NA	no (no)
	alveolar	voicing	NA	no (no)
	velar	voicing	NA	no
Yindjibarndi	labial	other	NA	no (no)
	dental	other	NA	no
	alveolar	none	NA	no (no)
	retroflex	other	NA	no
	palatal	none	NA	no (no)
	velar	other	NA	no
Yolngu (Djapu)	labial	other	NA	no (no)
	dental	other	NA	no
	alveolar	none	NA	no (no)
	retroflex	none	none	no
	palatal	other	NA	no (no)
	velar	other	NA	no

7.2 Stimuli for Experiment 1

7.2.1 Nasal-Stop Stimuli

Voiced Stops					
Labials		Coronals		Dorsals	
Stimulus	*EC*	*Stimulus*	*EC*	*Stimulus*	*EC*
amber	0.517	bandage	0.278	anger	0.336
ember	0.200	bandit	0.295	finger	0.436
limber	0.177	brandish	0.395	hunger	0.616
lumber	0.204	brandy	0.270	langor	0.181
mamba	0.443	pendant	0.394	linger	0.309
member	0.730	plunder	0.374	monger	0.053
number	0.618	ponder	0.348		
samba	0.438	slender	0.208		
slumber	0.621	tandem	0.327		
timber	0.551	thunder	0.264		

Voiceless Stops					
Labials		Coronals		Dorsals	
Stimulus	*EC*	*Stimulus*	*EC*	*Stimulus*	*EC*
campus	0.360	banter	0.144	anchor	0.167
compass	0.339	bounty	0.262	bonkers	0.639
hamper	0.232	canter	0.113	bunker	0.345
limpid	0.388	center	0.169	bunkum	0.147
pamper	0.227	counter	0.664	conquer	0.370
scamper	0.296	enter	0.394	donkey	0.558
scampi	0.250	jaunty	0.504	monkey	0.227
simper	0.317	saunter	0.273	pinkie	0.166
trumpet	0.388	shanty	0.350	rancor	0.126
whimper	0.363	vintage	0.454	tinker	0.175

7.2.2 Lenition Stimuli

Voiced Stops					
LABIALS		CORONALS		DORSALS	
Stimulus	*EC*	*Stimulus*	*EC*	*Stimulus*	*EC*
auburn	0.194	audit	0.195	beggar	0.182
baby	0.319	body	0.185	buggy	0.106
cabbage	0.265	cheddar	0.267	cougar	0.154
cabin	0.443	giddy	0.169	dagger	0.346
fiber	0.251	ladder	0.198	eager	0.260
labor	0.197	lady	0.201	ogre	0.105
lobby	0.250	odor	0.115	soggy	0.162
neighbor	0.228	radish	0.191	stagger	0.339
rabbit	0.225	rowdy	0.197	tiger	0.367
ribbon	0.450	shudder	0.294	trigger	0.405
rubber	0.263	spider	0.347	vigor	0.191
ruby	0.271	steady	0.228	yoga	0.435

Voiceless Stops					
LABIALS		CORONALS		DORSALS	
Stimulus	*EC*	*Stimulus*	*EC*	*Stimulus*	*EC*
copper	0.103	atom	0.207	acre	0.221
copy	0.137	attic	0.319	bacon	0.235
epic	0.326	autumn	0.268	bracket	0.352
guppy	0.224	beauty	0.379	broker	0.235
leopard	0.299	critic	0.300	bucket	0.396
opus	0.260	glitter	0.329	circuit	0.340
paper	0.179	item	0.347	flicker	0.340
puppet	0.364	lettuce	0.262	focus	0.470
rapid	0.311	pattern	0.362	khaki	0.223
super	0.190	pretty	0.297	package	0.223
topic	0.372	stutter	0.276	reckon	0.442
viper	0.174	votive	0.221	ticket	0.265

7.2.3 CVC Stimuli

Diphthongs							
[eɪ]		[oʊ]		[aɪ]		[aʊ]/[ɔɪ]	
Stimulus	*EC*	*Stimulus*	*EC*	*Stimulus*	*EC*	*Stimulus*	*EC*
bake	0.046	boat	0.054	bike	0.063	bout	0.050
base	0.055	coat	0.044	bite	0.044	doubt	0.096
cake	0.052	code	0.049	dice	0.069	douse	0.068
date	0.051	cope	0.051	fight	0.057	gout	0.047
fade	0.059	doze	0.068	height	0.052	pouch	0.085
gate	0.055	goat	0.059	hide	0.063	pout	0.044
gauge	0.052	hose	0.038	hike	0.053	shout	0.097
hate	0.051	poach	0.060	kite	0.035		
haze	0.042	poke	0.056	sight	0.046	choice	0.243
pace	0.041	soak	0.053	site	0.045	poise	0.092
pave	0.052	soap	0.069	tide	0.058	voice	0.221
shade	0.057	toad	0.057	tight	0.044	void	0.130

Front Vowels							
[i]		[ɪ]		[ɛ]		[æ]	
Stimulus	*EC*	*Stimulus*	*EC*	*Stimulus*	*EC*	*Stimulus*	*EC*
beef	0.060	bid	0.049	bed	0.061	bad	0.051
cheat	0.046	bit	0.050	bet	0.038	batch	0.045
deed	0.051	dip	0.057	dead	0.069	cat	0.043
heap	0.042	fit	0.045	deaf	0.072	chat	0.055
heat	0.045	hip	0.043	deck	0.053	fad	0.052
peak	0.042	hit	0.039	head	0.068	gash	0.043
piece	0.076	kick	0.052	jet	0.057	hat	0.045
seize	0.046	pick	0.056	pet	0.038	hatch	0.057
sheep	0.048	pitch	0.048	set	0.051	pack	0.047
sheet	0.042	sip	0.044	shed	0.055	pad	0.051
tease	0.050	sit	0.047	tech	0.047	patch	0.055
teeth	0.054	zip	0.058	vet	0.045	vat	0.052

Non-Front Vowels							
[u]		[ʊ]		[ʌ]		[a]	
Stimulus	*EC*	*Stimulus*	*EC*	*Stimulus*	*EC*	*Stimulus*	*EC*
boot	0.051	book	0.091	budge	0.056	botch	0.044
chute	0.042	cook	0.092	bug	0.042	cod	0.039
coop	0.032	hood	0.066	cub	0.049	cop	0.039
goof	0.065	hook	0.090	cuff	0.056	dock	0.056
goose	0.086	soot	0.051	cut	0.062	dot	0.039
hoop	0.040			duck	0.046	hawk	0.048
hoot	0.028			fuss	0.060	hop	0.055
pooch	0.018			huff	0.036	hot	0.060
poof	0.063			hut	0.051	jog	0.062
shoot	0.084			tub	0.063	pop	0.052
soup	0.070			tuck	0.052	shot	0.057
suit	0.061			tug	0.064	sock	0.056

7.3 Instructions for Experiments 2 – 4

7.3.1 Instructions for Experiments 2 and 4

Welcome Screen

Welcome!

During this experiment, you will listen to pairs of words. For each pair, you will indicate whether you heard the same word repeated twice, or two different words.

The words you will hear are not words from any particular language. Each word has the form “aCa”, where “C” is some consonant. So the vowels in each word are the same, but the consonant in the middle will change.

This experiment has five parts: a practice session, one long block, and three short blocks. You will have the option to take a break before each block.

Press the red button to begin the practice session.

Practice Instructions

During this session, you will practice responding to the types of words you will hear during the experiment.

After each pair of words, press the red button if you believe you heard two different words. Press the blue button if you believe you heard two repetitions of the same word. The experimental software will record your responses and let you know whether your answer was correct.

Please try to respond promptly to each pair. Although you should try your best, you're not expected to respond correctly to every pair of words, either in the practice session or during the experiment. If you find yourself frequently pausing while you try to decide on your answer, you're thinking too much!

The practice session will end once you have responded correctly to a certain number of pairs, or after five minutes, whichever comes first.

Press the red button to begin.

7.3.2 Instructions for Experiment 3

Welcome Screen

¡Bienvenido!

En este experimento, usted escuchará varios pares de palabras. Después de cada par, deberá señalar si ha escuchado la misma palabra repetida dos veces, o dos palabras distintas.

Las palabras que oirá no son palabras de ningún idioma en particular. Cada palabra tiene la forma "aCa", siendo "C" una consonante. Es decir, las vocales de cada palabra son siempre las mismas, pero la consonante del centro cambia.

El experimento consta de cinco partes: una sesión de práctica, una parte larga, y tres partes breves. Antes de cada parte, tendrá la oportunidad de tomar un descanso.

Para empezar con la primera parte (la sesión de práctica), por favor, pulse la tecla roja.

Practice Instructions

En esta sesión, usted practicará cómo responder a los pares de palabras que escuchará en el experimento.

Después de cada par de palabras, pulse la tecla roja si cree que escuchó dos palabras distintas. Pulse la tecla azul si cree que escuchó la misma palabra dos veces. El experimento registrará su respuesta y le informará de si era la correcta.

Por favor, intente responder con rapidez. Aunque debe concentrarse lo mejor que pueda, no se espera que dé la respuesta correcta para cada par (ni en la sesión de práctica ni en el experimento). Si se da cuenta de que se toma demasiado tiempo para decidir qué tecla pulsar, ¡se lo está usted pensando demasiado!

La sesión terminará bien después de que haya respondida correctamente a un numero suficiente de pares, bien tras cinco minutos, lo que suceda antes.

Pulse la tecla roja para empezar.

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