

The Nature of Optional Sibilant Harmony in Navajo

By

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Abstract

This thesis represents an attempt to gain a more precise understanding of optional sibilant harmony in Navajo through investigation of the first person possessive morpheme, which is underlyingly /ʃi-/ but may harmonize to [si-] when affixed to noun stems that contain [+anterior] sibilants. The literature commonly describes sibilant harmony as being mandatory in Navajo when sibilants are in adjacent syllables, and optional when there is more distance between sibilants. In other words, sibilant disharmony is ungrammatical, but gradiently rather than categorically; in some instances disharmony is ungrammatical enough that it must be repaired through assimilation, while in other instances it is less ungrammatical and may be tolerated. The statistical nature of the variation in these optional harmony settings is not fully understood, however, and the three studies contained within this thesis were designed to investigate how often assimilation occurs in nonmandatory environments and to identify factors that contribute to the variability observed.

In the first study, a Google search was used to evaluate sibilant harmony in online Navajo language use in the Spring of 2008 and again in the Spring of 2010. The findings present a picture of optional sibilant harmony that differs somewhat from the traditional view; harmony seems to be optional even in the environment that has traditionally been described as mandatory, and it occurs far less frequently than anticipated.

These results led to the creation of an online survey wherein fluent speakers of Navajo provided grammaticality judgments of both assimilated and unassimilated forms. Almost universally, respondents preferred the unassimilated [ʃi-] even in those environments where assimilation would previously have been considered mandatory.

The third study involved the recording of data from three speakers of Navajo, none of whom use the assimilated *si-* either in writing or in speech—at least, not to a degree that is discernible to the naked ear. Acoustic analysis was performed to determine whether /ʃ/ is acoustically consistent across the board—duration, spectral mean, onset of frication energy, and the second formant of the following vowel were measured to investigate whether the prefixal [ʃ] differs acoustically when it appears before words that contain potential triggers than when it does not. Analysis reveals some differences in the spectral mean and duration of the fricative portion of the first person possessive morpheme when it occurs before stems that contain [+anterior] sibilants.

Taken together, the findings presented herein suggest that the mandatory sibilant harmony environment no longer exists in Navajo, at least with regards to the first person possessive morpheme. Harmony is far less prevalent than expected overall, and is wholly absent for some speakers. The factors of continuancy and adjacency were found to contribute significantly to the gradience observed in all three studies, however, even for those speakers who do not overtly use assimilation.

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1 Introduction

Sibilant harmony in Navajo is a phonological phenomenon requiring sibilants within a word to have identical specifications for the feature of anteriority, such that a word can contain alveolar sibilants or palatal sibilants but may not contain both. This has been referred to as a distance-dependent process, occurring mandatorily when stem sibilants are in a syllable adjacent to the prefix and optionally when they are in non-adjacent syllables (Sapir & Hoijer 1967). Neither the factors contributing to the optionality nor the statistical nature of the variation in optional settings is fully understood, however, and these are the issues addressed in this thesis.

The Introductory section begins with an overview of consonant harmony in general and sibilant harmony in Navajo in particular, outlining the phonological process itself and reviewing previous studies. It then transitions into a discussion of gradience, a topic which is of great interest in the field of phonology and for which sibilant harmony in Navajo provides rich ground for exploration. Previous studies dealing with gradience are presented, and the overarching research questions tackled herein are laid out. The Introduction concludes with a summary of the present work, so that the reader has a sense of what to expect as they proceed through the thesis as a whole.

1.1 Consonant Harmony

Broadly, harmony systems within languages require participating segments to agree with regards to specific features. Vowel harmony systems, which have been well-documented, may require some or all vowels in a word to agree with regards to, for example, backness, roundness, or advancement of tongue root (Bakovic 2000). Consonant harmony is a less common phenomenon, and the specific characteristics of consonant harmony systems—including the type of segments that are affected and the reach of the agreement constraints imposed by harmony—vary from language to language. A key feature of consonant harmony as a phonological process, however, is that it operates at a distance and intervening segments are unaffected (Hansson 2001, Rose and Walker 2004). This is referred to as *action-at-a-distance* by Rose and Walker (2004), and is illustrated in (1) with an example of nasal assimilation from Kikongo, a Bantu language.

- (1) a. m-[bud-idi]_{stem} “I hit”
b. tu-[nik-ini]_{stem} “we ground”

(from Rose and Walker 2001, p. 475)

As seen above, the voiced oral stop in the suffix assimilates in nasality when a voiced nasal appears earlier in the stem. The vowels and voiceless oral stop that

intervene are completely unaffected by this harmony process; the only segments that participate are the nasal which is the trigger and the voiced oral stop which is the target. This is the sense in which consonant harmony operates at a distance. In Kikongo, the trigger for assimilation—in (1b), the stem-initial nasal—can be at any distance from the target in the suffix as long as it is within the domain of the stem, but nasals outside of the stem do not trigger harmony, as demonstrated by the fact that the nasal in the prefix in (1a) does not trigger assimilation. The concept of distance is interesting because, as shown above, it can be measured in various ways—for example, by segments, by syllables, or by morphemes, among others. In Kikongo, the number of intervening segments within the stem does not matter but the stem boundary does. This topic will be addressed in more detail in Section 1.3.1.

Multiple types of consonant harmony have been documented, including—but not limited to—liquid harmony, nasal harmony, dorsal harmony, laryngeal harmony, and coronal harmony, which is perhaps the most widely attested form of consonant harmony (Hansson 2001, Shaw 1991). Coronal harmony can be further sub-divided into non-sibilant harmony and sibilant harmony. In his dissertation on consonant harmony, Hansson (2001) conducted an extensive typology of attested consonant harmony systems; he reports that sibilant harmony is the predominant type of consonant harmony, accounting for approximately one third of the harmony systems surveyed in his work (p. 55). Sibilant harmony is a feature of various indigenous North American language families; those most often discussed include the Chumashan family and the Athabaskan family, of which Navajo is a member.

1.2 Sibilant Harmony in Navajo

Navajo is an indigenous North American language spoken in what is now the southwest corner of the United States. The Ethnologue reports that there are 149,000 speakers, but this estimate is based on figures from the 1990 U.S. Census and should be interpreted accordingly. A general phonotactic constraint within Navajo disallows sibilants of conflicting anteriority feature specifications within a word (McDonough 2003, Martin 2005). The segments that participate in this process in Navajo are laid out in (2). Note that for the rest of this thesis, the descriptors [+anterior] and *alveolar* will be used interchangeably; [-anterior] and *palatal*¹ will be used interchangeably as well.

(2) Navajo Sibilants

[+ANTERIOR]	[-ANTERIOR]
/s/	/ʃ/
/z/	/ʒ/
/ts/	/tʃ/
/ts ^h /	/tʃ ^h /
/ts' /	/tʃ' /

¹ The [-anterior] segments in Navajo are sometimes referred to as postalveolar, but I will consistently use the term palatal.

This constraint ensures that roots containing a mismatch such as **[t̥soo]* or **[t̥ʰoo]* do not exist, and when morpheme concatenation creates a disagreement prefixal sibilants assimilate to the anteriority value of sibilants within the root to which they attach. Navajo sibilant harmony is overwhelmingly anticipatory; that is to say, the rightmost sibilant in a word controls the anteriority specification of all other sibilants. If the root contains no sibilants, prefixes may also assimilate to the anteriority value of subsequent prefixes.

Harmony is commonly discussed as being mandatory in some environments in Navajo—within certain domains of verbal morphology, for example (Fountain 1998, McDonough 2003, Weisser 2008), but disharmony is sometimes tolerated. In discussing optional sibilant harmony in Navajo, Sapir and Hoijer (1967) list a number of allomorphic alternations that result from harmony and note that these alternations “are not compulsory,” but are in part “conditioned by the distance between the prefix consonant and that to which it is assimilated” (p. 14). This is demonstrated in examples (3 – 6) below. Triggers—those segments whose anteriority controls the harmony—are underlined with a single line. Targets—whose anteriority specification may be changed by harmony—are underlined with a double line.

- (3) a. [yɪʃ t̥ʰid] “to scratch it”
 b. [yɪʃ tsʰiis] “to drag it”

(from McDonough 2003, p. 50)

(4) a. [s̥i-ʔá] “a round object lies”

b. [ʃi-dʒaa] “a mass lies”

(from Sapir & Hoijer 1967, p. 15)

In (3), the underlyingly palatal sibilant in the prefix surfaces faithfully in (3a) but is realized as an alveolar [s] when affixation causes it to be adjacent to an alveolar sibilant in (3b). In (4), the underlyingly alveolar [s] in the prefix surfaces faithfully in (4a) but is realized as [ʃ] in (4b) when it is affixed to a stem containing a palatal sibilant. Note that the difference between (3b) and (4b) is in terms of adjacency; in (3b), the sibilants are adjacent to one another segmentally, while in (4b) the sibilants are in adjacent syllables. Sapir and Hoijer make no distinction between these two types of adjacency, saying only that “assimilation nearly always occurs when the two consonants are close together, but it occurs less often when the two consonants are at a greater distance” (p. 14-15).

Examples (3) and (4) can be contrasted with (5) and (6), in which harmony is optional and disharmony is tolerated.

(5) a. [ná-ʃi-dii-ʔ-tsáás] “you lash me once with a whip”

(from Sapir & Hoijer 1967, p. 15)

(6) a. [ʔa-tʃii-ł-táás] “he (4th p.) bends things”

OR

b. [ʔa-tsii-ł-táás] “he (4th p.) bends things”

(from Sapir & Hoiyer 1967, p. 15)

The underlying palatal sibilant in the prefix in (5) is at a distance from the sibilants in the root; here, it surfaces faithfully and disharmony is tolerated. Yet distance does not nullify a potential trigger-target relationship between sibilants; an anteriority mismatch created by morpheme concatenation may either be tolerated, as indicated by the grammatical unassimilated form in (6a), or it may be repaired by assimilation as indicated by the assimilated form in (6b). Put plainly, an anteriority mismatch in Navajo may be dispreferred when sibilants are at some distance from one another, but not to the same degree as when they are closer to each other.

The optional harmony environment provides rich ground for phonological investigation because optionality results in both morphophonological variation and gradient grammaticality. The terms *variation* and *gradience* are widely used, and so it is worth taking a moment to explain how they are used here. *Variation* is used in this thesis as defined by Coetzee and Pater (2009); specifically, the term is used to refer to “the situation in which a single morpheme can be realized in more than one phonetic form in a single environment” (p. 1). Variation may manifest both within

the productions of a single speaker and across speakers. The forms shown in (6) are an example of this kind of variation.

Gradience is used broadly to refer to anything that is not categorical—to illustrate this, we can consider categorical and gradient phonotactics. Some forms are wholly illegal and are simply prohibited; English phonotactics disallow a form like [ɲih], for example. Others are dispreferred, but are not disallowed—[sf] is not an illegal onset cluster in English, yet it is underrepresented in the lexicon, making words like *sphinx* and *sphere* unusual rather than ungrammatical (Hammond 2004). As will be discussed in the next section, gradience can also be found in speaker grammaticality judgments; between the two poles of *grammatical* and *ungrammatical* lies a whole range of *more* grammatical and *less* grammatical. Sibilant harmony restrictions in Navajo may be seen as gradient if we consider that mismatches are not simply allowed or disallowed; rather, adjacent anteriority mismatches are *less* tolerated, while nonadjacent mismatches are *more* tolerated.

We now turn to a more thorough discussion of gradience, a topic in which linguists are increasingly interested.

1.3 Variation and Gradience in Phonology

Gradience presents a challenge to phonological theories wherein rules or constraints are conceived of as being categorical (Boersma and Hayes 2001, Frisch and Zawaydeh 2001, Hammond 2004). In both the traditional rule-based generative

phonology framework and in the original incarnation of Optimality Theory (Prince and Smolensky 1993), rigid phonotactic generalizations lead to a black-and-white assessment of forms as being absolutely grammatical or absolutely ungrammatical. Yet languages are full of gradience. Certainly there are forms which are completely ungrammatical or completely grammatical, but these are perhaps best thought of as opposite ends of a single spectrum. Forms can be deemed good or bad, but they can also be deemed better or worse.

Various models for dealing with gradience have been proposed, including Maximum Entropy grammars (Eisner 2000, Johnson 2002, Hayes and Wilson 2008), Harmonic grammar (Smolensky 1986, Smolensky and Legendre 2006), and Stochastic Optimality Theory (Boersma 1997, Boersma and Hayes 2001). In a Stochastic Optimality Theory grammar, for example, phonological constraints occupy a bell-shaped probability distribution; the ranking of each constraint may fall anywhere within its distribution in a given instance, and the probability distributions overlap to greater or lesser degrees such that the specific ranking of constraints may vary each time a form is generated.

The functional result of such a model is variation; multiple phonetic forms may emerge depending on the specific ranking that is evoked in a given production. Variation is relevant in the present work in that an individual speaker of Navajo may produce different forms of a word in optional sibilant harmony environments. Recall, for example, the words given in (6), repeated here for ease of reference.

(7) a. [ʔa-tʃii-ʔ-táás] “he (4th p.) bends things”

OR

b. [ʔa-tsii-ʔ-táás] “he (4th p.) bends things”

(from Sapir & Hoijer 1967, p. 15)

If we posit the existence of both a markedness constraint that penalizes sibilant anteriority mismatches in Navajo words and a faithfulness constraint that penalizes departures from the underlying representation, then the unassimilated form in (7a) will surface when the faithfulness constraint outranks the markedness constraint, and the assimilated form in (7b) will surface when the markedness constraint outranks the faithfulness constraint. In this way, models like that proposed by Stochastic OT can account for both the existence of variation in individual speaker data (because different constraint rankings can be generated in different instances of production) and for gradient patterns in the lexicon. While this thesis seeks to use an accumulation of individual speaker data to shed light on trends in the lexicon as a whole, bear in mind that it is the way in which gradience contributes to those overall trends that is of the greatest interest.

In addition to developing theoretical models that can account for gradience, researchers are also engaged in investigating gradience on multiple levels. Of particular interest here is the body of literature that looks at the relationship between gradient grammaticality judgments and the statistical composition of the lexicon. It has been well established that speakers give gradient responses when asked to judge the wellformedness or wordlikeness of nonsense words (Ohala and

Ohala 1986, Frisch et al 2000). Hammond (2004), for example, notes that when asked to determine the wellformedness of the wug word [blɪk], English speakers judge it to be “better than” [sfɪk] (p. 2). As previously mentioned, the English lexicon is not devoid of words that begin with [sf], as evidenced by *sphinx* and *sphere*, and [sfɪk] does not violate English phonotactics—it could be an acceptable word of English. If grammaticality judgments were categorical we would expect speakers to rate the word as either grammatical or not, yet the intuition for English speakers is that [sfɪk] is neither absolutely good or absolutely bad; it is merely acceptable.

It has also been demonstrated that these kinds of gradient grammaticality judgments are affected by both the frequency of the phonological pieces within nonsense words and by their neighborhood density (Bailey and Hahn 2001, Coleman 1996, Ohala and Ohala 1986). To determine the phonological frequency of a form like [blɪk], for example, we would determine the probability of a [bl] onset and the probability of an [ɪk] rime and multiply them; to determine its neighborhood density, we determine the number of real words it is ‘similar to,’ this being generally defined as any word that can be formed by changing a single sound. Thus [flɪk], [brɪk], and [blæk] are counted when determining the neighborhood density of [blɪk]. Bailey and Hahn (2001) have shown that the two factors can be manipulated independently, and that both have a significant effect on speakers’ wellformedness judgments. In fact, current research is leading to a more and more nuanced picture of the factors that affect gradience. Three factors of phonological

relevance—distance, perceptual salience, and similarity—will be addressed in the following sections.

Before proceeding, it is important to point out that distance and similarity could actually be subsumed under salience. With distance, for example, it could be argued that a closer segment has more salience as a trigger for phonological processes. The same can be said for similarity; increased similarity between two segments—one a trigger for and the other the target of a given phonological process—may make the trigger more salient. That being said, the three factors are given their own sections in the following discussion, because distance and similarity are of such import in the consonant harmony literature.

1.3.1 Distance

The elicitation of grammaticality judgments of phonological wellformedness is only one method that has been utilized by researchers to investigate phonological gradience; it has also been investigated via statistical analyses of dictionaries and lexicons, and several recent works have demonstrated that distance-related gradiency is reflected in the statistical make-up of the lexicon. In looking at constraints dealing with Obligatory Contour Principle (OCP) violations related to place of articulation of consonants in Arabic roots, Frisch et al. (2004) searched an online Arabic lexicon and found that while roots like **ssm* are most strongly prohibited, additional smaller-scale, more gradient patterns also exist in the lexicon.

While **ssm* clearly violates the OCP, adjacent homorganicity is also dispreferred in roots; accordingly, roots like *stm* are underrepresented. Nonadjacent homorganicity is dispreferred as well, but to a lesser degree, so that roots like *smt* are underrepresented but not to the same degree as roots like *stm*. In other words, distance affects gradiency, and this relationship is statistically evident within the Arabic lexicon.

Although these findings reflect the make-up of the lexicon of Arabic rather than individual speaker knowledge, Frisch and Zawaydeh (2001) conducted a similar study in which grammaticality judgments were used to gather information about speaker awareness of gradience in the lexicon. In this study, the researchers elicited wellformedness judgments of novel verbs from native speakers of Jordanian Arabic; their findings suggested not only that speakers were aware of the OCP Place constraints in Arabic, but they also reflected the gradiency found in previous dictionary-based studies.

Evidence of distance-related gradience has also been found in the English lexicon. Berkley (2000) reports that pairs of similar consonants near one another are not found as often as would be predicted by chance alone in English and Latin words. She refers to this as the OCP effect, and finds that it is most evident when the consonants in question are separated by a single vowel and becomes less pronounced as additional segments intervene. In her words, “the closer two consonants are to each other stringwise, the less likely it is for them to be similar to each other” (p. iii). Distance depends not only on the number of segments

intervening between a pair of consonants, however; the OCP effect is weaker across syllable and morpheme boundaries, even when consonant pairs are separated by the same number of segments. This is interesting because it highlights the fact that distance can be calculated using different metrics—in this case, by segments, by morphemes, and by syllables.

Distance-related gradience and the various ways in which distance can be measured have been investigated in Navajo, as well. Recall that Sapir and Hoijer (1967) made reference to distance in their commentary about sibilant harmony in Navajo, stating that it was mandatory when sibilants were near one another and optional when they were more distant from one another. Martin (2005) used an online Navajo lexicon to investigate gradience, with a focus on Navajo compounds. When Navajo noun stems which contain sibilants with conflicting anteriority values are compounded, the resulting phonotactic violation can be dealt with in multiple ways: two options are that one stem can assimilate, to repair the violation, or the violation can be tolerated. A third alternative is that compounds with underlying sibilant anteriority disagreement can be avoided. When Martin searched an online Navajo lexicon composed of 11,000+ words, he found 211 compounds that contained exactly two sibilants, one in each root. Forms with underlying sibilant disagreement were statistically underrepresented in the Navajo lexicon as a whole, suggesting that that third option—avoidance of a violation through non-formation of a compound—is a viable choice. For the compounds that contained underlying

anteriority mismatches, however, distance entered the equation as a relevant factor with regards to the fix employed.

In words that contained sibilants in adjacent syllables, the sibilants agreed in anteriority 70% of the time. In words containing sibilants in nonadjacent syllables, anteriority agreement reached approximately 44%; in other words, an anteriority mismatch was tolerated more than 50% of the time when the sibilants were in nonadjacent syllables (Martin 2005, p.16). These findings show a bias towards assimilation when the sibilants in a compound are in adjacent syllables, but no such bias when the sibilants are in nonadjacent syllables. In other words, distance—measured here in terms of adjacent versus nonadjacent syllables—matters. An anteriority mismatch in adjacent syllables is worse than one in nonadjacent syllables, and is more often repaired through assimilation. A nonadjacent mismatch is not as bad, and is more often tolerated.

Like Berkley (2000), Martin performed an analysis in order to determine how best to calculate distance in Navajo, and found a statistically significant difference in assimilation rates between sibilants separated by the same number of segments but by different syllabification. For two sibilants separated by three intervening segments, those in adjacent syllables agreed with regards to anteriority 72% of the time while those in nonadjacent syllables agreed 27% of the time (p. 18). Martin also assessed assimilation rates of sibilants in adjacent syllables separated by varying numbers of segments, and found no significant difference in agreement rates as the number of intervening segments increased. This indicates that when

considering distance-related gradience in Navajo sibilant harmony, distance should be measured by syllable and not by segment.

Taken together, then, the above studies highlight distance as a factor that contributes to gradience, but distance is not the only factor that has been found to contribute to gradience. Next we turn to a discussion of similarity, which is of import not only in consonant harmony systems but also in a number of other phonological domains.

1.3.2 Similarity

Although the specific metrics which are used for calculating similarity may vary from language to language, the relevance of similarity arises repeatedly. There has been a great deal of research, for example, focused on OCP-Place restrictions in Arabic verbal roots (Frisch and Zawaydeh 2001, Pierrehumbert 1993). Within OCP-Place research, place of articulation groupings are further divided; coronals in Arabic, for example, can be broken into sonorants, obstruent stops, and obstruent fricatives, and verbal root restrictions in Arabic most strongly prohibit consonant-consonant sequences that share both place and manner of articulation. In other words, consonant pairs are more strongly prohibited when the consonants are more similar to one another. Thus a root like **stm* which has a pair of similar consonants—i.e., consonants that are homorganic but that differ with regards to manner of articulation—is dispreferred, but is not as strongly prohibited as a

sequence which shares both place and manner specifications (Coetzee and Pater 2008, Frisch et al 2004).

Similar findings are reported for the western Austronesian language Muna, with statistical analysis of a Muna lexicon revealing influence from gradient OCP-Place restrictions (Coetzee and Pater, 2008). The strength of the restriction is related to the similarity of the consonants involved; sequences of homorganic consonants are gradiently restricted, and the gradient is influenced not only by place of articulation but also by manner and by voicing specification. Voicing has not been shown to play a strong role in the Arabic data, wherein sonorancy agreement is a strong predictor of underrepresentation, but in Muna consonants which agree with regards to voicing are treated as more similar to one another than consonants with the same manner of articulation but contrasting voicing specifications. Thus ND sequences are more underrepresented than DT sequences, which in turn are more underrepresented than NT sequences. This indicates that place, manner, and voicing agreement all play an important role in determining similarity with regards to OCP restrictions in Muna.

The Arabic and Muna data help illustrate the fact that the metric by which similarity is calculated may vary between languages. Berkley (2000) shows that gradient OCP effects limit the occurrence of 'similar' consonant pairs in both English and Latin words, but that similarity is calculated differently in the two languages. In Latin, coronal consonants that are close to one another violate the OCP, and words containing two coronal consonants near one another are underrepresented in the

lexicon. Analysis of the English lexicon indicated that while pairs of coronal consonants near one another are somewhat underrepresented, thereby showing evidence of OCP effects, coronals are farther subdivided into sonorants and obstruents; words containing two coronal sonorants or two coronal obstruents near one another are more underattested than words containing a coronal sonorant and a coronal obstruent near one another. Thus similarity is relevant to the strength of the OCP restrictions in both languages, but the factors which determine how similar two consonants are to one another differ. Latin is sensitive to place, while English is sensitive to place and manner.

Discussion of both the import of similarity and crosslinguistic variation with regards to how similarity is calculated feature heavily in MacEachern's 1997 dissertation on laryngeal co-occurrence restrictions. A survey of 11 typologically distinct languages reveal an implicational hierarchy; predictions about restrictions can be made based on the other restrictions that are present or absent in the language. Further, differences in the typology of the languages' co-occurrence restriction result from different similarity metrics. Languages exhibit differences in the degree of similarity between segments which is tolerated. A given pair of consonants—for example, ND—may be different enough in one language for co-occurrence to be tolerated, but similar enough in another for co-occurrence to be restricted. Thus similarity can be seen to play a key role in the way similar co-occurrence restrictions play out in various languages.

Similarity is also of critical importance in the aggressive reduplication constraint proposed by Zuraw (2002). Zuraw notes pseudo-repairs made to words which have built-in similarity, such as *orangutan*, which is ‘repaired’ to *orangutang*, and *Okefenokee*, which is repaired to *Okeefonokee*, and posits that these altered forms arise when the word already contains “sufficient internal phonological self-similarity” (p. 396). A reduplication constraint that establishes and enforces a correspondence between similar strings is proposed, and loan-word phonology in Tagalog is investigated. In Tagalog, the mid vowels [o] and [e] are generally found only in word-final syllables for native words. When mid vowels are moved into penultimate syllables through suffixation, vowel raising to [u] and [i] often occur. Mid-vowels in non-ultima positions are more tolerated in loanwords than in native words, however, and Zuraw finds that the vowel-raising customarily found in native words is blocked in loan words that contain other mid vowels. In other words, when there is a highly similar sequence of sounds due to the presence of a mid vowel elsewhere in the word—particularly when it is in an adjacent syllable, and when the two mid vowels match with regards to backness—mid vowels are tolerated in positions where they would typically be ungrammatical in order to satisfy the reduplication constraint.

Moving now from the important role played by similarity in assessing gradient OCP and co-occurrence restriction violations, and in establishing correspondence between segment sequences in aggressive reduplication as proposed by Zuraw, let us consider its role in consonant harmony systems. That

similarity is of importance in these systems is widely acknowledged. Rose and Walker (2001) state that the “similarity of agreeing consonants is central to the typology” of consonant harmony systems, and that “similarity plays a decisive role in identifying which segments stand in correspondence” (p. 3, 5). They demonstrate that consonant agreement systems are typified by the similarity of the consonants involved in the harmony processes; sibilant harmony systems involve only fricatives and affricates, for example, while dental/alveolar harmony systems affect only stops (Rose and Walker 2001). Hansson (2001) notes that although many kinds of harmony systems exist, and the features for which they require segments to match varies widely, they are “frequently sensitive to the relative similarity of the interacting consonants” (p. 1).

The reduplication and consonant harmony data add nicely to the OCP-Place and Laryngeal Co-Occurrence restrictions discussed previously, for a variety of reasons. Firstly, while some of those studies dealt with gradient speaker judgments, many were dictionary-based statistical analyses which showed the effects of gradient restrictions on the composition of the lexicon. The reduplication patterns Zuraw investigates can be looked at synchronically, however; we can investigate active application by speakers. Secondly, in reduplication and consonant harmony similarity serves as the basis for a correspondence rather than a restriction; in these types of processes, a degree of shared similarity institutes a requirement for identity—rather than avoidance of similarity. In coronal harmony systems, for example, consonants which already share a general place of articulation assimilate

with regards to place and manner specifications which are *only* relevant to coronals; they are already similar, and harmony enforces an identical featural specification.

Moving now beyond distance and similarity, we next consider a number of factors which I will group together under the heading of salience; those addressed herein include stress, syllable position, and manner of articulation.

1.3.3 Salience

Salience has different meanings in different contexts and in linguistics, some of these meanings are very specific. The term is used here in a broad manner, indicating anything that is especially noticeable or important. This could include features, segments, or word or syllable positions. Recall that, as noted by Hansson 2001, sibilant harmony is the predominant type of consonant harmony attested in the world's languages; it is worth considering that this is precisely because sibilants are exceptionally salient segments. While a great many linguistic factors can be noticeable or important in different contexts, at present we are interested in phonologically important factors that contribute to gradience. Finally, distance and similarity are interconnected with and relevant to saliency given the above definition. However, they are discussed separately in sections 1.3.1. and 1.3.2 because they are conceptually distinct.

The definition of saliency provided above may be likened to what Beckman (1998) refers to as “perceptually or psycholinguistically prominent” (p. viii).

Beckman's discussion focuses primarily on positions that are of prime perceptual or psycholinguistic salience, noting a number of positional asymmetries in terms of both contrast neutralization and preservation and in terms of segments which serve as triggers for or targets of phonological processes. Segments in root initial syllables, stressed syllables, and syllable onset position, for example, often retain featural contrasts that would be lost elsewhere; in addition, segments in these positions are more likely to be triggers for and less likely to be targets of processes such as vowel harmony.

The saliency of the syllable as a phonological unit has also been demonstrated in perception research. In a review of various experimental approaches commonly used in research focused on speech perception, Sendlmeier (1995) determined that while listeners are able to shift their focus to smaller or larger units depending on the task at hand, "as a default case, the syllable serves as the primary perceptual unit" (131). This is a nice complement to the syllable-based measure of distance supported by the findings discussed in Section 1.3.1 (Berkley 2000, Martin 2005). Additionally, some syllables are more salient than others; Sendlmeier (1987) found that syllables in word onset position and stressed syllables were of particular significance in a nonword similarity task—which, as noted by Frisch (2000), is a task that shares many similarities with the nonword grammaticality judgment tasks discussed previously. When participants were asked to make similarity judgments for nonwords, Sendlmeier found that word onsets and

stressed syllables were especially salient for naïve listeners; these listeners made categorizations based on salient characteristics alone.

Stressed syllables and those in word-initial position were also shown to be particularly salient in Berkley (2000). Recall that Berkley found a gradient OCP effect in English; words with similar consonants near one another are not found as often as chance alone would predict. In addition to the distance-related gradience discussed in 1.3.1—the effect weakens across syllable and morpheme boundaries—Berkley also found asymmetries in the strength of the OCP effect based on stress and word position, with the OCP effect being stronger in stressed syllables than in unstressed syllables, meaning that consonant pairs in stressed syllables are less likely to be similar to one another than consonant pairs in unstressed syllables. Similar consonant pairs are more strongly prohibited in initial syllables than in non-initial syllables, as well. Similar patterns have also been found in English speech error data, with similar consonant pairs in syllables earlier in the word more prone to errors than those in syllables later in the word (Frisch 2000) and consonant onsets in stressed syllables more prone to errors than onsets in unstressed syllables (Shattuck-Hufnagel 1985).

With regards to syllable position, it has been demonstrated in a variety of tasks—ranging from production and perception experiments to first language acquisition research focused on the development of phonological awareness—that onsets are more salient than codas. One traditional view of the syllable in English and close relatives proposes that it is composed of two primary units—the onset

and the rime (Berg 1989, Fowler 1987, Selkirk 1982, Stemberger 1983). To address the concern that a number of the experiments underlying this view of the syllable involved the use of monosyllabic words—which, in essence, could result in a confusion of syllable effects with word effects—Treiman et al. (1995) designed a series of studies using disyllabic and trisyllabic words. These studies involved groups of undergraduate students learning novel word games. Students performed better at games involving substitution of onset consonant than at those involving substitution of coda consonants; interestingly, they also performed better when asked to substitute an entire rime than when asked to substitute a syllable onset and the following vowel. These findings were taken to support an onset-rime syllable structure and highlight the importance of the onset as a salient syllable position.² Berkley (2000) found syllable position to be significant in her analysis of gradient OCP effects in the English lexicon, as well—the OCP effect was weaker across onset-coda consonant pairs than across onset-onset consonant pairs, again supporting a view of onsets as being particularly salient.

Moving beyond the syllable as a unit of measurement and the importance of syllable position, we now consider manner of articulation. The relevant question here is whether we can make statements regarding the salience of particular manners of articulation. One hint may be found in a slightly different area of research than that which we have considered thus far; in the arena of child language

² It is worth noting that Treiman et al. (1995) also found onset consonants in stressed syllables were found to be more salient than those in unstressed syllables, which highlights the fact that multiple factors contribute to salience—such as word position, syllable position, and prosodic features like stress.

research, we find that when children are tested for phonological awareness they are better at identifying noncontinuants than continuants (Treiman et al, 1998). This suggests that noncontinuants may be more salient than continuants, which is relevant to the present work because while some would debate the continuancy status of affricates, they are consistently referred to as noncontinuants in this thesis due to the features they share with stops. The descriptor *continuant*, then, is used to refer to the sibilant fricatives [s, z, ʃ, ʒ] in Navajo, while that of *noncontinuant* is used to refer to the sibilant affricates [ts, dz, tʃ, dʒ].

In a concise accounting of perceptual studies related to stops, affricates, and fricatives, Shinn (1985) notes that several key works on the affricate-fricative distinction classify affricates as distinct from fricatives because, like stops, they have a release burst; fricatives do not. Gerstman made merely passing reference to this feature of affricates when noting about the synthetic speech used in his 1957 stop-affricate-fricative perception study that his stimuli were unlike natural speech because the stops and affricates lacked a release burst, and Dorman et al. (1980) noted the perceptual salience of the release burst in a study about fricative/affricate perception in word-final position. While these studies do not deal directly with the strength of noncontinuants—and specifically affricates—as triggers for phonological processes, they do raise the possibility of noncontinuants being more salient, perhaps due to the associated release burst.

The final factor which will be discussed in relation to salience is referred to in a study of Hungarian vowel harmony by Hayes et al. (2009) as *count effect*.

Hungarian vowels can be classified into the three categories *back*, *front rounded*, and *front unrounded* (henceforth *neutral*). The dative suffix in Hungarian takes two forms, [-nək] and [-nɛk], the appearance of which is dictated by vowel harmony restrictions. The environments in which one of the allomorphs is used mandatorily are not relevant here, but the two environments where variation occurs are. When attaching to stems with either a *back-neutral-(neutral)* or *neutral-(neutral)* vowel pattern—in other words, stems containing one back and one or two neutral vowels, or stems containing one or two neutral vowels only—either allomorph may surface. Both are acceptable. The data shows a count effect, however; words containing two neutral vowels in the string are more likely to take the front suffix [-nɛk] than those that contain only a single neutral vowel. Recall that vowels designated as neutral are in fact front unrounded—in other words, these vowels are [+front]. Words containing two neutral vowels, then, contain more frontness, for they contain two vowels with a [+front] specification.

This same phenomenon is referred to as *trigger count* in Hayes and Londe (2006). The argument is that multiple segments acting together are a stronger trigger for harmony than a single segment. Neutral vowels are weaker triggers for frontness than back vowels are for backness in the example from Hungarian, but when two team up their strength increases. In the domain of vowel harmony, there are cases where harmony only applies when two triggers are present (Walker 2001). If this phenomenon is mirrored in consonant harmony, then the presence of

multiple triggers will render them more salient, thereby increasing the likelihood of harmony applying in an optional setting.

To review, then, research from speech production, speech perception, child literacy, the development of phonological awareness, speech errors, and statistical analysis of dictionaries and lexicons highlight a number of factors that may be phonologically salient and underlie gradience.

1.3.4 Summary

This section began with commentary about gradience in phonology, and then moved into a discussion of some of the factors that have been shown to influence gradience in both the lexicon, as reflected in dictionaries and word lists, and in speakers' mental grammars, as reflected by a range of measures from grammaticality judgments and speech errors to perception and production tasks. The broad factors addressed included distance, similarity, and salience. Salient factors included stress, syllable position, and manner of articulation among others. What we have not yet done is discuss how sibilant harmony in Navajo relates to gradience.

1.4 Gradience and Sibilant Harmony

Optional sibilant harmony presents an opportunity to investigate gradience in Navajo, for if harmony is sometimes mandatory and sometimes optional then the ungrammaticality of sibilant anteriority mismatch cannot be categorical. Rather, anteriority mismatches are bad enough that they must be repaired in some instances, and are tolerated in others. We lack a clear understanding of this gradience, however; we do not know how often harmony applies in optional settings, nor do we know which factors contribute to the gradience.

One hint might be found in Martin (2005), who searched an online Navajo lexicon for words containing exactly two sibilants. The search returned a total of 589 words; in the 276 words that contained one sibilant in an affix and the other in a root, anteriority agreement reached almost 100%. Clearly, not all of these words necessarily underwent assimilation; some of them must have had no underlying mismatch. Those that did, however, assimilated. They showed none of the distance-related gradience that was evident in his findings related to compound words (see section 1.3.1).

These findings make it look as though harmony was always mandatory, for to achieve a near-100% agreement rate harmony must have applied nearly every time the chance arose. This search was performed using an online lexicon, however, and if it is true that sibilant harmony is optional in certain environments in Navajo—as is widely accepted—then these results cannot be assumed to accurately reflect real-world language use. This is confusing, however, if we think back to Frisch and

Zawaydeh (2001), in which speaker awareness of gradient OCP Place constraints aligned with previous findings from dictionary-based studies. This begs the question: what is the true statistical nature of the optionality? How often does harmony apply in optional settings in real language use, and can we find factors beyond distance that contribute to the variability? These are the overarching questions that I will attempt to answer in the following sections.

1.5 Summary of the Current Project

This project consists of three studies. First, the online search engine Google is used to assess assimilation rates of the first person possessive morpheme /ʃi-/ in online Navajo language use, with some startling results. Harmony applies far less often than anticipated, and the mandatory environment for harmony no longer seems to exist. Next, grammaticality judgments of assimilated and unassimilated forms of nouns inflected for the first person are gathered from fluent users of Navajo via an internet survey in an attempt to determine which factors beyond distance affect optional assimilation. Again, the results indicate that the unassimilated form of the prefix is heavily favored in all environments, but the data suggest that distance is still relevant and that manner of articulation and syllable position of the stem sibilant may also contribute to gradient judgments of grammaticality. Finally, three speakers of Navajo who show no overt signs of harmonizing are recorded and their speech is analyzed to determine whether alveolar stem sibilants affect the prefixal sibilant in ways that are perceptually

undetectable but acoustically measurable. Findings indicate that the answer is yes for all three, although the acoustic parameters affected are somewhat different from person to person. The final section of the thesis ties the findings from all three studies together, discusses challenges faced in the collection of data, and lays out plans for future investigation.

2 Experiment I: Assimilation in Online Language Use

The study discussed in the following pages used the search engine Google to investigate assimilation rates of the first-person possessive morpheme /ʃɪ-/ in nouns containing [+anterior] sibilants in online Navajo language usage, which is possible because this assimilation is reflected orthographically in Navajo. The unassimilated form of the prefix is spelled *shi-*; the assimilated form, wherein the underlyingly palatal sibilant harmonizes in place of articulation to match an alveolar sibilant in the root, is spelled *si-*. Recall that the prefix *shi-* is expected to surface as *si-* mandatorily when affixed to nouns that contain an alveolar sibilant in a syllable adjacent to the prefix, and optionally when the stem sibilant is in a nonadjacent syllable. Broadly, Experiment I aims to answer two major questions.

- I. What is the statistical nature of the variation in the optional assimilation environment? More plainly: when assimilation is optional, how often does it occur?
- II. What factors contribute to the variation in assimilation rates in optional environments?

Before proceeding, we can make both a broad prediction regarding mandatory and optional harmony environments as well as specific predictions regarding the factors that may contribute to the variability seen in optional assimilation. Factors investigated in this study include voicing, continuancy, adjacency, syllable position, and number of stem sibilants. Predictions related to each factor will be spelled out individually, but underpinning them all are the notions of distance, salience, and similarity discussed in Section 1.3.1.

2.1 Predictions

2.1.1 Mandatory and Optional Assimilation Environments (Distance)

The first person possessive morpheme will assimilate to *si-* mandatorily when affixed to nouns that contain an alveolar sibilant in an adjacent syllable, as seen in (8), and optionally when the alveolar sibilant appears in a non-adjacent syllable, as seen in (9).

(8) /ʃɪ-/ + tsili → sitsili *my younger brother*

/ʃɪ-/ + ziiz → siziiz *my belt*

(9) /ʃɪ-/ + béeso → sibéeso *my money*

OR

shibéeso *my money*

This prediction is based on the distance factor; a segmental measurement of distance is precluded in this study because of the form of the morpheme under investigation—the prefixal sibilant will never be adjacent to a stem sibilant stringwise, because the prefixal vowel will always intervene. However, using the syllable as a basic measure of distance is supported in general by Sendlmeier (1995), for English by Berkley (2000), and for Navajo by Martin (2005).

2.1.2 Voicing (Similarity)

Agreement in voicing specification makes the stem sibilant a better trigger for assimilation. Since the prefixal sibilant in question is voiceless, [s] and [ts] will be better triggers than [z] and [dz], respectively.

2.1.3 Continuancy (Similarity/Saliency)

If similarity is of the utmost importance in establishing a correspondence agreement between sibilants that will trigger harmony, then agreement with regards to the manner of articulation makes the stem sibilant a better trigger; because the prefixal sibilant in question is a continuant, [s] and [z] will be better triggers than [ts] and [dz], respectively.

If, on the other hand, saliency contributes to the optionality, then based on the manner of articulation findings reported in 1.3.3 the noncontinuant [ts] and [dz] will be better triggers for assimilation than the continuants [s] and [z], respectively.

2.1.4 Adjacency (Distance)

A sibilant in an adjacent syllable is a more likely trigger than a sibilant in a nonadjacent syllable. This is the distance factor again, à la Martin (2005), but differs from 2.1.1; that prediction centers around defining mandatory and nonmandatory environments, while this one deals with the location of a specific sibilant.

2.1.5 Syllable Position (Similarity/Saliency)

Both similarity and saliency support a prediction of stem sibilants in onset position acting as more likely triggers; similarity because of onset allophony—the

prefixal sibilant is in onset position—and salience because of the findings about the salience of onsets presented in 1.3.3.

2.1.6 Number of Sibilants (Salience)

Multiple sibilants in a stem are more likely to trigger assimilation than a single stem sibilants. This is the *count effect* or *trigger effect* referred to in Hayes and Londe (2006) and Hayes et al. (2009). The prediction here is that there is power in numbers—that if a stem contains multiple stem sibilants which agree in anteriority, their strength as triggers is pooled, resulting in increased salience.

2.2 Procedure and Materials

To test these predictions, a list of Navajo nouns containing alveolar sibilants was created and Google was used to search for tokens affixed with the first person possessive morpheme.

2.2.1 Noun List and Sample Size

Using the noun list in Young & Morgan's 1992 *Analytical Lexicon of Navajo*, the New Oxford Navajo-English Picture Dictionary, Wall & Morgan's Navajo-English Dictionary, and a bilingual children's book by J.B. Enochs entitled "Little Man's

Family,” I compiled a list of 157 Navajo nouns that contained at least one [+anterior] segment. A few examples appear in (10), and a complete list of the 29 nouns which returned useable results can be found in Appendix A: QueryGoogle Noun List and Assimilation Rates.

(10) Sample Noun List

1. béeso	<i>money</i>	5. látsíní	<i>bracelet</i>
2. kaz	<i>cane</i>	6. mósí	<i>cat</i>
3. k'is	<i>friend</i>	7. naaltssoos	<i>book</i>
4. k'os	<i>neck</i>	8. tsii'	<i>hair</i>

For each stem, I then used a combination of the QueryGoogle software package developed by Bruce Hayes and Kie Zuraw and a Google search by hand to look for tokens affixed with both forms of the first person possessive prefix—the assimilated *si-*, and the unassimilated *shi-*.

Two points regarding sample size should be made at the outset. First, the noun list is relatively small, and second, it was often the case that very few tokens were found for each noun. Why was this the case? With regards to the first point, there were a number of complicating factors involved in creation of the noun list. Although the Young & Morgan noun list alone contains 2245 entries, many of them do not contain alveolar sibilants and were therefore ineligible for this study. The pool of eligible nouns was further limited by orthographic transfer issues. Navajo

orthography utilizes several segments which are difficult to render online; for example, high-toned nasalized vowels in Navajo are written with both an accent mark and a nasal hook, e.g. [á̃]. This combination did not yield useable hits on Google; words containing high-toned nasalized vowels were not found. The noun list was also limited by the fact that some nouns simply cannot be reasonably possessed. It is far more reasonable to say ‘my money,’ for example, than ‘my sky.’ (Even in English, it is relatively difficult to find the string ‘my sky’ online—except where it refers to a trademarked television service called Sky.)

It should also be noted that I made simplifications when searching. The word for money, *béeso*, includes a tone mark on the first [e], indicating a falling tone; I searched for the word both with and without the tone mark, and got more hits for the simplified *beeso* than for the correct *béeso*, indicating that others utilize the same sorts of simplification when entering Navajo text onto web pages and blogs.³

After the list was limited by the factors mentioned above, it was further shortened by the fact that online Navajo data proved to be less robust than anticipated, both in the spring of 2008 and in the spring of 2010. Google returned zero results for even the unaffixed form of many nouns. In total, I searched 157 noun stems, each affixed with both *si-* and *shi-*; the 29 nouns listed in Appendix A are the only stems that yielded usable results. (Note that while there are 29 nouns total, there are only 28 nouns tallied for Spring 2008 and Spring 2010 results; one noun was found in 2008 but not 2010, and vice versa.)

³ Interestingly, though perhaps not surprisingly, simplified forms were especially prevalent on social networking sites like Facebook and MySpace.

2.2.2 QueryGoogle and a by-hand search

The initial search for affixed forms was performed using QueryGoogle. If QueryGoogle found no examples of the word on the internet, the word in question was excluded from my list. All words for which QueryGoogle returned hits were retained, and subjected to a search by hand. When a word returned a reasonable number of hits, it was generally the case that I found the word on Navajo web pages when I did a search by hand. For example, QueryGoogle showed two hits for *shilatsini* (my bracelet), and a search by hand found two tokens of *shilatsini* on Navajo language web pages. (Note that *látsíní* in fact contains all high-toned vowels, but the online hits contained no accents.) When a word returned tens or hundreds of thousands of hits, it generally meant that the word was composed of good syllables in languages other than Navajo. In those instances, I used a Boolean search to limit the field. QueryGoogle returned tens of thousands of hits for both affixed forms of *das*, ‘weight’; *shidas* and *sidas* are apparently “good” words in many languages. The by-hand search strings for these words, then, were “*sidas* AND Navajo,” and “*shidas* AND Navajo.”

2.2.3 Calculating Assimilation Rates

A total of 604 tokens were found in Spring 2008; that number jumped to 1,669 in the spring of 2010. Sample data are shown in (11), and full results can be found in Appendix A.

(11) Sample Google Results

WORD	PROPORTIONS (SI-FORMS/TOTAL NUMBER OF TOKENS FOR STEM)		ASSIMILATION RATES ADJUSTED FOR RELIABILITY	
	SPRING08	SPRING10	SPRING08	SPRING10
-tsa	1/1	4/6	0.35	0.43
-tsiits'iin	8/8	12/16	0.79	0.60
-za'azis	1/1	2/2	0.35	0.50
-ziiz	96/98	142/145	0.95	0.95
-zee	17/18	9/15	0.82	0.45
-k'is	232/309	488/886	0.72	0.53

Before moving into a thorough reporting of results, it is important to mention that the assimilation rate for each word can be determined in at least two different ways. The raw assimilation rate may be determined by dividing the number of assimilated forms by the total number of hits. This information can be found in the Proportions column, where the total number of assimilated forms found by Google appears as the numerator and the total number of hits (assimilated and unassimilated) appears as the denominator. Consider the word *ziiz*, 'belt,' for which

Google returned 145 hits in Spring 2010, 142 of them for the assimilated form *siziiz* and three of them for the unassimilated *shiziiz*. The raw assimilation rate of *ziiz* can then be calculated as $142/145$ or 0.98. Meanwhile, *za'azis*—pocket—appeared online twice in Spring 2010, taking the form *siza'azis* both times and therefore yielding a raw assimilation rate of $2/2$ or 1.0. *Za'azis* thus ends up with a slightly higher raw assimilation rate than *ziiz*; the prefix assimilated to *si-* 100% of the time that it attached to *za'azis*.

The problem is that on an intuitive level, 100% of two instances and 98.62% of 145 instances do not seem to hold equal weight. In fact, it has been shown that we trust things less and are less willing to make phonological generalizations when we have very little evidence, while we trust things more and are more willing to make generalizations when we see many attestations (Albright et al. 2001, Pierrehumbert 2006). How, then, should we determine assimilation rates? To answer this question, we turn to the concept of Adjusted Reliability proposed by Mikheev (1997) and utilized by Albright, Andrade, and Hayes (2001). Albright et al. used Adjusted Reliability to rate various phonological rules, some of which applied in all environments where they could apply but could apply only in a very few instances and others of which could apply in a vast number of instances and applied in many, but not all, of those instances. They argued that “we intuitively give greater credence when testimony is more abundant” (Albright et. al. 2001, 121). In other words, two rules should not be considered equal when one of them has a significantly higher number of attestations.

In the current study, the intuition is that assimilation rates should be adjusted for reliability to reflect the strength of the evidence, which in this case is total number of hits. Following Albright et. al. 2001, Adjusted Reliability is defined as the lower limit of the 0.75 confidence interval. Exact confidence intervals were calculated for each proportion. Thus, when adjusted for reliability, the Spring 2010 assimilation rate of *ziiz* is 0.957 while that of *za'azis*, with far few tokens, is 0.5.

2.3 Results

Before reporting the results, it is important to make note of something that will be relevant throughout the remainder of this thesis, namely the potential conflation of factors being analyzed. Consider, for example, a word like *shik'is*, 'my friend.' The stem sibilant in this word is a continuant in coda position in a syllable adjacent to the prefix. A word like *shitsili*, 'my younger brother,' contains a noncontinuant in syllable onset position in a syllable adjacent to the prefix. A further complication arises from syllable structure constraints; as readers can observe in the noun lists found in Appendices A and B, noncontinuants only appear in onset position. Thus when comparing assimilation rates of stems containing noncontinuants with those of stems containing continuants, the noncontinuant stem group contains only sibilants in syllable onsets while the continuant stem group contains continuants in both onset and coda position. In this way, manner of articulation and syllable position are conflated. This is an important issue, and

while sample sizes in the present work do not allow for the disentanglement of these factors it remains to be addressed in future work.

The sample consisted of 28 nouns, with a Spring 2008 overall adjusted assimilation rate mean of 0.358 ($SD = 0.31$) and a Spring 2010 overall mean of 0.348 ($SD = 0.27$). Independent samples t tests were conducted to determine whether assimilation rates varied significantly based on the voicing, continuancy, adjacency, syllable position, or number of alveolar stem sibilants. The results for these comparisons will be presented one at a time, but because of the small sample size and number of tokens it should be stated at the outset that assumptions of normalcy were met for all conditions except adjacency. Skewness and kurtosis were within normal limits for the other four variables (Tabachnick & Fidell 2007); the adjacency distribution was slightly skewed, so the nonparametric Mann-Whitney U test was used.

As will be noted in the discussion, the most startling finding in this study was the nonexistence of a mandatory harmony environment; in online use of the first person possessive morpheme, *shi-* is a viable option even when affixed to a stem that begins with an alveolar sibilant. Assimilation is always optional.

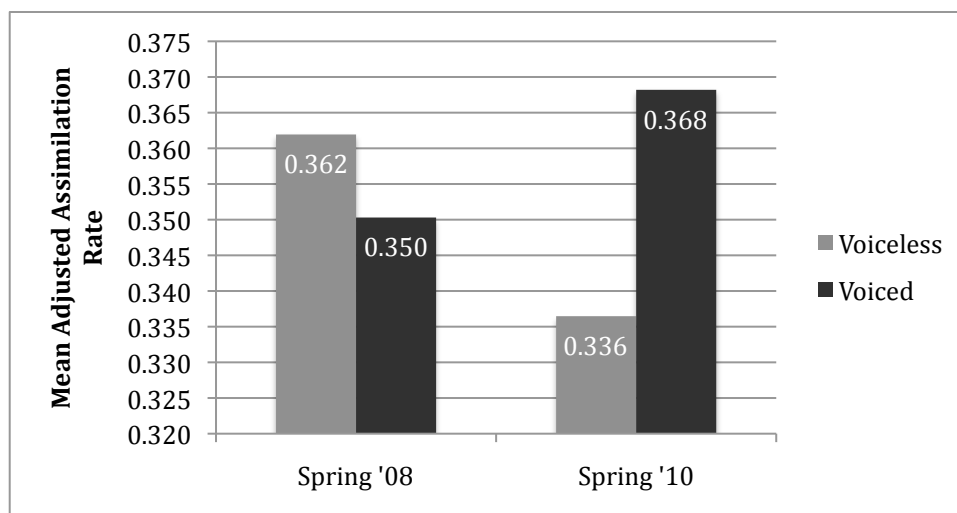
2.3.1 Voicing

Independent samples t tests were conducted on both the 2008 and 2010 data to evaluate the hypothesis that stem sibilants which match the prefixal sibilant in

voicing act as stronger triggers for assimilation. Since the prefixal sibilant in question is voiceless, nouns containing voiceless sibilants ($N = 16$) should show a higher mean assimilation rate than those containing voiced sibilants ($N = 10$).⁴ The test was neither significant for 2008, $t(25) = 0.092$, $p = 0.464$, nor for 2010, $t(25) = -0.29$, $p = 0.387$. The prefix did not assimilate more when attaching to nouns containing voiceless sibilants than when attaching to nouns containing voiced sibilants.

Further, the voiceless group showed a slightly higher mean in 2008 while the voiced group showed a slightly higher mean in 2010, as seen in (12). While neither difference is significant, it is interesting to note that the difference was in opposite directions in the two years.

(12) Mean Adjusted Assimilation Rates: Voicing



⁴ Stems that contained both voiced and voiceless alveolar sibilants were excluded from the calculations; thus the total number of nouns included in the voicing calculations was 26 rather than 28. This holds throughout; stems containing both continuant and noncontinuant alveolar stems were excluded from the continuancy calculations, and so forth.

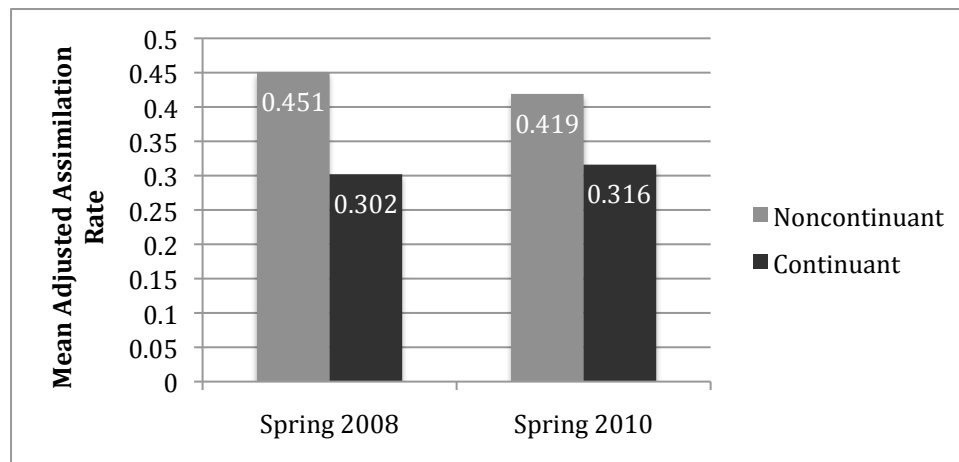
The feature of voicing will be investigated in the following studies, but it bears mentioning that these results are not entirely surprising. While the phonetic inventory of Navajo is fairly rich, with laryngeal contrasts in stops and affricates and many coronal segments, phonemic contrasts based on voicing appear only in fricatives (McDonough 2003, p. 2-4). Further, in Navajo as a whole many contrasts are neutralized outside the domain of verb and noun stems. Thus while the distinction between /s/ and /z/ is both phonemic and relevant in the domain of noun stems, voicing is not heavily utilized as a distinctive feature in Navajo as a whole.

2.3.2 Continuancy

An independent samples *t* test was conducted to determine whether stem sibilants which match the prefixal sibilant in continuancy were stronger triggers for assimilation. As the prefixal sibilant is the continuant [ʃ], stems containing noncontinuants ($N = 9$) should produce lower assimilation rates than those containing continuants ($N = 16$). The test was neither significant for 2008 ($t(23) = 1.165, p = 0.128$) nor for 2010 ($t(23) = 0.926, p = 0.182$). Mean adjusted assimilation rates did not differ significantly based on the manner of articulation of the stem sibilant. However, the noncontinuant group showed a numerically higher assimilation rate mean than the continuant group in both years, as seen in (13). The

difference is not significant, but suggests that the salience of noncontinuants may be a stronger factor than similarity. This bears additional investigation in future work.

(13) Mean Adjusted Assimilation Rates: Continuancy



2.3.3 Adjacency

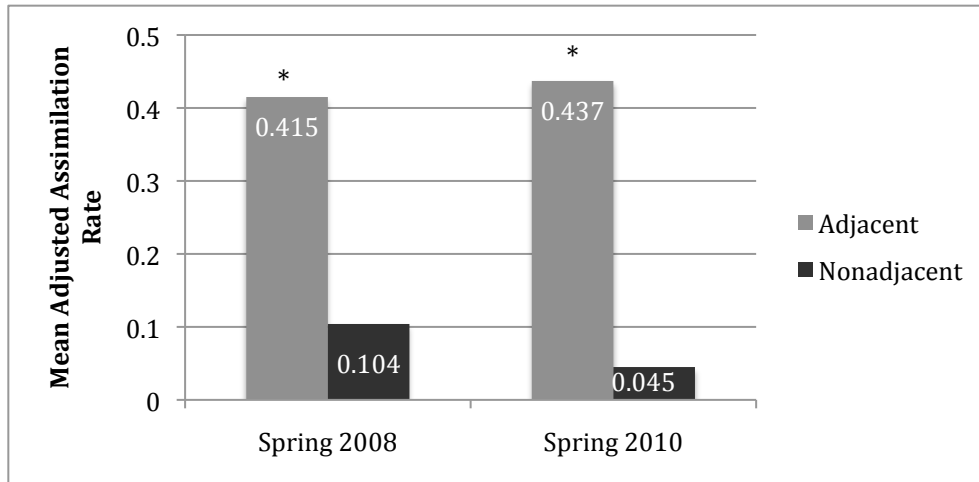
Assumptions of normal distribution were not met for the adjacency condition; because the 2010 sample was skewed, a nonparametric measure was used in addition to the Independent Samples *t* test. Both sets of values are reported below.

An independent samples *t* test was conducted to evaluate the hypothesis that nouns with [+anterior] stem sibilants in adjacent syllables ($N = 19$) would show higher mean adjusted assimilation rates than those with [+anterior] sibilants in nonadjacent syllables ($N = 6$). The test was significant for both years, with 2008

values of $t(23) = 2.338, p = 0.014$ and 2010 values of $t(23) = 6.736, p = <0.001$.

Mean adjusted assimilation rates are provided in (14).

(14) Mean Adjusted Assimilation Rates: Adjacency



Eta squared was calculated to determine the effect size for the normally distributed Spring 2008 results. The equation used appears in (15); it yielded an η^2 value of 0.192, indicating a relatively large effect size (Green & Salkind 2008).

(15) Eta Square for Independent-Samples t Test

$$\eta^2 = \frac{t^2}{t^2 + (N_1 + N_2 - 2)}$$

As previously noted, the Spring 2010 results were skewed and equal variances could not be assumed. Thus a Mann-Whitney *U* test was conducted to assess whether the mean adjusted assimilation rate of the prefix was significantly higher for nouns containing sibilants in adjacent syllables than for those containing sibilants in nonadjacent syllables. The results were significant and in the expected direction for both years, $z = 2.58$ and $p = 0.01$ for 2008 and $z = 3.312$ and $p = 0.001$ for 2010. Nouns containing sibilants in nonadjacent syllables had an average rank of 6.25 in 2008 and 4.33 in 2010, while those containing sibilants in adjacent syllables had a mean rank of 15.13 in 2008 and 15.74 in 2010.

These results taken together suggest that, as all previous work has indicated, distance plays an important role in optional sibilant harmony in Navajo. Under the old definition, harmony was mandatory when the stem sibilant was in an adjacent syllable and optional when it was nonadjacent the twist revealed by these results is that harmony is never mandatory in online Navajo use of the first person possessive morpheme, but happens significantly more often when the stem sibilant is in an adjacent syllable.

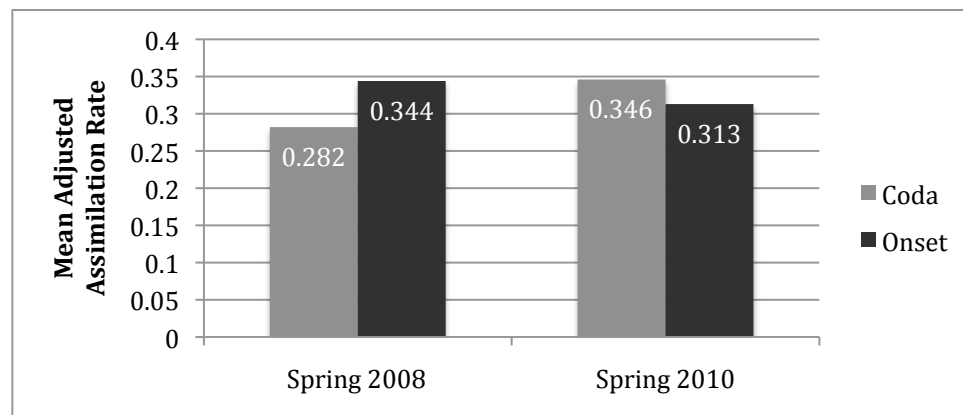
2.3.4 Syllable Position

An independent samples *t* test was conducted to evaluate the hypothesis that stem sibilants which match the prefixal sibilant in syllable position will act as stronger triggers for assimilation. As the prefixal sibilant is in onset position, nouns

containing alveolar sibilants in onset position ($N = 18$) should evidence higher mean adjusted assimilation rates than nouns containing sibilants in coda position ($N = 5$). Note that we will not be able to distinguish a similarity effect from a salience effect in this instance, as onset position is both similar and salient.

The test was not significant in either year; 2008 values were $t(21) = 0.406$, $p = 0.3445$, while 2010 values were $t(21) = -0.216$, $p = 0.398$. As demonstrated in (16), while the difference in means was not significant, the findings were in the expected direction for 2008 but not for 2010.

(16) Mean Adjusted Assimilation Rates: Syllable Position

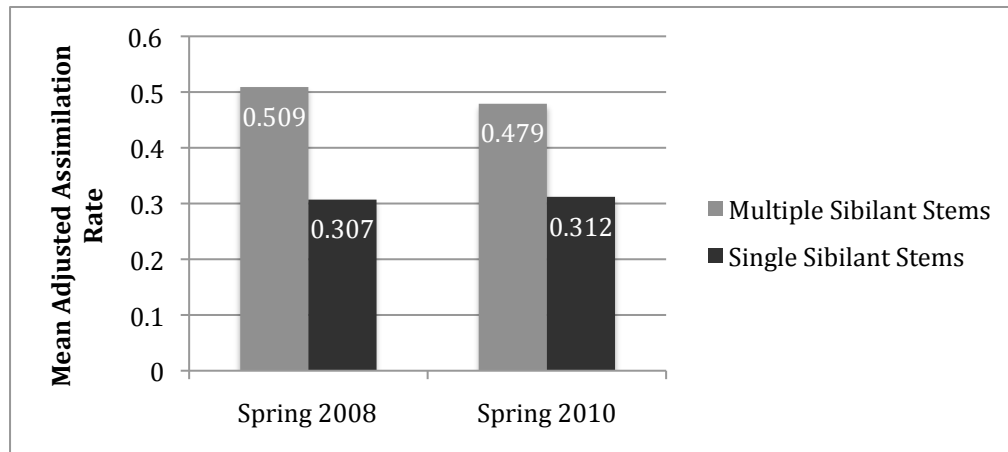


2.3.5 Number of Stem Sibilants

An independent samples t test was conducted to evaluate the hypothesis that stems with multiple sibilants ($N = 7$) act as stronger triggers for assimilation than stems with a single sibilant ($N = 20$). The test approached significance for both

2008, $t(25) = 1.564$ and $p = 0.065$, and for 2010, $t(25) = 1.465$ and $p = 0.078$. Group means are shown in (17).

(17) Mean Adjusted Assimilation Rates: Number of Stem Sibilants



2.4 Discussion

This study would benefit from more data—both in terms of the number of nouns searched and in terms of the number of tokens found for each noun—but the results exhibit some exciting trends that warrant discussion. The most basic observation we can make is that sibilant harmony in general is far more optional online than is indicated in dictionaries or in previous work with speakers. Recall that Prediction 2.1.1 dealt with what have traditionally been described as the mandatory and optional assimilation environments, and stated that harmony should apply mandatorily when the *shi-* prefix attached to nouns with an alveolar sibilant in an adjacent syllable. According to the findings of this study, however, the

mandatory assimilation environment no longer exists—at least with regards to the first person possessive morpheme, and at least in the domain of online language use. Users of Navajo tolerated sibilant anteriority mismatches online even in that formerly mandatory environment—i.e., when the conflicting sibilants were in adjacent syllables. For example, there were fifteen hits for the word for ‘my mouth’ in Spring 2010—nine were the assimilated *sizee*, and 6 were the unassimilated *shizee*.

If assimilation in the mandatory environment was not mandatory at all, then it is unsurprising that assimilation rates in the optional environment were relatively low. In fact, the overall mean adjusted assimilation rate hovered around 35%—0.358 in 2008, and 0.348 in 2010. This mean includes not only the nouns with the “optional” assimilation environment, but those with the “mandatory” environment as well. Statistically, the nature of this assimilation is very different than the near-100% anteriority agreement rates found by Martin (2005) for affixed words in the online Young et al. lexicon. Assimilation patterns seem to differ between dictionary and real-life use.

Adjacency remains relevant, however—which is not a surprise, given the number of studies that have indicated that distance plays a vital role in phonological gradience (Berkley 2000, Frisch and Zawaydeh 2001, Frisch et al. 2004, Martin 2005). Even if adjacency no longer constitutes a mandatory harmony environment in the online Navajo usage surveyed in this study, it was the one factor that had a significant effect on assimilation rates. Nouns containing anterior sibilants in

adjacent syllables showed significantly higher assimilation rates than those whose anterior sibilants were in nonadjacent syllables. In other words, even though assimilation occurs less frequently than anticipated, distance matters—and it matters gradiently, not categorically.

A comparison of the mean assimilation rate of nouns with multiple anterior stem sibilants versus those with a single stem sibilant did not turn up a significant result, but the test approached significance. This suggests that the possible existence of a count effect should not yet be discounted, and additional investigation would be of value. Significant differences in assimilation rates in this study were not based on the voicing or syllable position of the stem sibilants, but these factors will be examined in more detail in the next section.

The continuancy specification the stem sibilant did not yield significant results, either, but the trend in both years suggests that noncontinuants may be stronger triggers for assimilation than continuants. This is very interesting; if this finding is replicated in future studies, it would support an analysis wherein the salience of affricates trumped the similarity of fricatives.

There are many possible explanations for the patterns observed in this study, all of which could be addressed in future work. Internet language use may or may not be an accurate reflection of real world language use; users might be fluent Navajo speakers, but they may also be passive users of Navajo who have incorporated a few words into websites or blogs. Passive users may be copying words as chunks rather than concatenating morphemes themselves. Several people

create Navajo graphics and greeting cards which can be sent over MySpace and Facebook; hypothetically, if a single individual creates a greeting card with an unassimilated form of a possessed noun on it, and the card is then copied onto 50 or 100 peoples' homepages, then the unassimilated form is being propagated by chance rather than by choice. This sort of factor complicates the scenario.

It is also possible that the Navajo language use found online is representative of a younger, more technologically-oriented generation; younger people are accustomed to emailing and text-messaging, forms of communication in which abbreviation of words and avoidance of punctuation and other formalities is the norm. Thus the modification of search terms by eliminating nasal hooks and accent marks and so forth may inadvertently target younger users who are more comfortable modifying and simplifying the orthography. The use of orthographic shortcuts or modifications is a loaded issue in some language communities, where it is seen as disrespectful, yet evidence from MySpace and personal blogs indicates that teen-aged and college-aged users of Navajo do not hesitate to simplify orthography. Further research may therefore reveal that the results of this study reflect a very specific population of users who are comfortable with informal language use in an informal domain; for now it remains an open question.

On a slightly different note, it was distressing to find that online Navajo language use was so scarce, and that use increased only slightly from the spring of 2008 to the spring of 2010. Navajo is the most-spoken Indigenous language of North America—speaker number estimates vary widely, ranging from fewer than

100,000 to as many as 200,000 speakers—and yet no Navajo corpus nor any great reserve of Navajo-language web pages exists. The Navajo Nation daily newspaper is available online, but it is primarily in English. The internet can provide an arena for investigating the ways in which current speakers are using the language in electronic interactions, but this potential pool of data is only useful for languages that are well-represented online. On the optimistic side, it seems that Navajo language use is on the rise on social networking sites such as Facebook and MySpace; if these trends continue, the amount of Navajo language online will continue to increase. The data reported in this study

2.5 Conclusion

The Google study outlined above answers some questions, and raises many more; while sibilant harmony in Navajo has been discussed as a mandatory phenomenon in certain phonetic contexts, these results indicated that the mandatory environment has in large part disappeared. Yet even with harmony occurring so much less frequently than anticipated, at least one factor was shown to contribute significantly to the variation. Distance is the factor that has been most often referenced in past discussion of optional sibilant harmony in Navajo, and these findings indicate that distance—measured syllabically in terms of adjacent versus nonadjacent syllables—maintains importance.

The other factors which were investigated did not return significant results, and so to further investigate the Google findings, an online survey designed to elicit grammaticality judgments from users of Navajo was deployed.

3 Experiment II: The Grammaticality of Assimilated Forms

The study discussed in section 2 indicated that sibilant harmony occurred less frequently than anticipated in online language use. There was a great deal of optionality, even in the environment where harmony was previously thought to be mandatory; in fact, the mandatory environment was no longer found to exist. Because the study was affected by the fact that it focused on the potentially informal domain of online language use, yielded a small sample size, and utilized some forms whose orthography had been simplified by dropping accent marks, nasal hooks, et cetera, an online survey was designed to elicit more nuanced information about assimilation patterns from fluent users of Navajo.

Like the Google study, this survey investigated assimilation rates of the first-person possessive morpheme /ʃɪ-/ in nouns containing [+anterior] sibilants. The previous study indicated that assimilation occurs far more infrequently than anticipated—and is, seemingly, never mandatory—and so the current study was designed to answer two major questions.

- Do users of Navajo who do not show evidence of assimilation in their own writing nonetheless show variability when grammaticality judgments are elicited?
- If they do, can that variability be analyzed according the factors previously investigated—i.e., voicing, continuancy, adjacency, syllable position, and number of stem sibilants?

The predictions for this study closely mirror those of the Google study, with one major exception. The prediction regarding a mandatory assimilation environment is removed; we proceed under the assumption that there is no longer a mandatory assimilation environment for the first person possessive morpheme, and instead introduce Prediction 3.1.1.

3.1 Predictions

3.1.1 Targets vs. Fillers

Nouns containing alveolar sibilants (henceforth, targets) will receive lower grammaticality ratings when affixed with the unassimilated *shi-* form of the prefix than those containing no alveolar sibilants (henceforth, fillers); fillers will be deemed less grammatical than targets when affixed with the assimilated *si-* form. For example, in (18) *sichaii* should be deemed ungrammatical, because it contains no triggers for assimilation and as such should never be affixed with the assimilated

si-. Based on the Google findings, however, both *sitsoi* and *shitsoi* in (19) may be deemed grammatical; assimilation may not be mandatory, but could be triggered by the alveolar [ts].

(18) /ʃɪ-/ + chaii = shichaii/*sichaii *my maternal grandfather*

(19) /ʃɪ-/ + tsoi = sitsoi/shitsoi *my cross cousin*

3.1.2 Voicing

Similarity with regards to voicing specification makes the stem sibilant a better trigger. The prefixal sibilant is voiceless, so stems containing [s] and [ts] will receive higher grammaticality ratings than those containing [z] and [dz], respectively.

3.1.3 Continuancy

If the contribution of similarity outweighs that of salience in establishing a correspondence between trigger and target sibilants, then continuancy agreement will make the stem sibilant a better trigger. The sibilant in the prefix is a continuant, so stems containing [s] and [z] will receive higher grammaticality ratings than those containing [ts] and [dz], respectively. If, on the other hand, salience outweighs similarity, then we would expect to see an extension of the trend suggested in the

Google results—i.e., the assimilated form of stems containing noncontinuants will receive higher mean grammaticality ratings than the assimilated forms of stems containing continuants.

3.1.4 Adjacency

A sibilant in an adjacent syllable is a more likely trigger than a sibilant in a nonadjacent syllable. Stems containing sibilants in adjacent syllables will receive higher grammaticality ratings than those with sibilants in nonadjacent syllables.

3.1.5 Syllable Position

Whether similarity or salience plays a bigger role in determining the strength of a trigger, the predictions with regards to syllable position are the same; a sibilant in onset position is a better trigger than one in coda position, and so stems containing sibilants in onset position are expected to receive higher grammaticality ratings when assimilated than those with sibilants in coda position.

3.1.6 Number of Stem Sibilants

The strength of stem sibilants as triggers is additive; stems that contain multiple sibilants are more likely to trigger assimilation than those that contain a

single sibilants. Multiple sibilant stems will receive higher grammaticality ratings than single sibilant stems.

3.2 Procedure and Materials

3.2.1 Noun List

To test these predictions, the list of 75 Navajo nouns found in Appendix B was compiled. It is composed of 50 target nouns which contain alveolar sibilants and 25 fillers. Fillers contain either palatal sibilants or no sibilants at all—in both cases, there is no trigger for assimilation and forms affixed with the harmonized *si-* should be deemed ungrammatical.

None of the included nouns required accent marks or nasal hooks on vowels. Some are quite common nouns; others are somewhat less common. For additional commentary on individual nouns, please refer to the notes at the end of Appendix B.

3.2.2 Survey

The survey was created using Qualtrics Survey Software (Qualtrics Labs, Inc. 2010), Version 14258 of the Qualtrics Research Suite. Use of Qualtrics was made possible by an agreement entered into by Qualtrics and the University of Kansas College of Liberal Arts and Sciences. The results discussed herein are from 20 participants—the total number accrued in the first year of its existence—but the

survey will remain open for an indeterminate amount of time. While it remains open, it can be found at http://kuclas.qualtrics.com/SE?SID=SV_0HuPHOLzLezGtZq. The survey URL may be freely distributed, and questions about the survey should be directed to kelly764@ku.edu.

The grammaticality assessment survey took two forms. In its first incarnation, participants were asked to provide the first-person possessed forms of various nouns in addition to giving grammaticality judgments on both assimilated and unassimilated possessed forms. An example of this is seen in (20).

(20) Qualtrics® Survey: Version 1 Screenshot

Qualtrics.com

The next part of this survey contains 75 nouns. Some of the words will be unfamiliar to you, so a definition is provided below each word. For every word that is given, you are asked to fill in the blank with the appropriate term. Here are two examples.

Example A: In Example A below, you are given the Navajo word meaning 'his plan.' To respond to this question, type the Navajo word that means 'my plan' in the blank below.

his plan: binahat'a

my plan: _____

Next, you will be asked to rate the acceptability of several words—to give your opinion of whether or not they are good Navajo words.

If a word looks perfectly natural to you, and is what you would say, you might give it a rating of GREAT.

If a word seems very unnatural, and you cannot imagine anyone saying it, you might give a rating of TERRIBLE.

For Example A, please rate the acceptability of the word *shinahata*'.

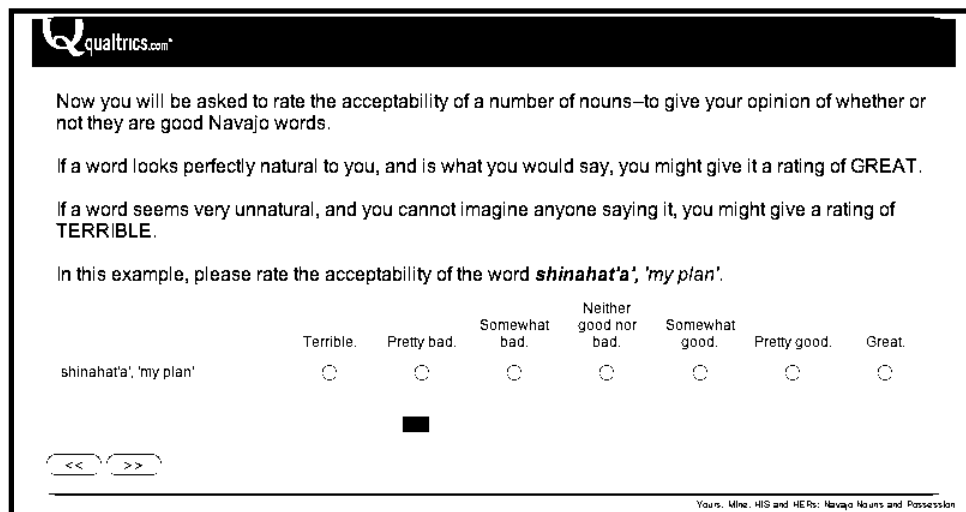
	Terrible.	Pretty bad.	Somewhat bad.	Neither good nor bad.	Somewhat good.	Pretty good.	Great.
shinahata'	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

<< >>

Yours, Mine, HIS and HERs: Navajo Nouns and Possession

Participants were recruited via postings on Facebook, MySpace, and Craigslist, as well as on the Linguistic Society of America’s Linguistlist and both the Athabasckan and Endangered Languages listservs hosted by the LSA. A total of seven responses were gathered in as many months; these results showed that participants used the unassimilated *shi-* prefix almost exclusively, supporting the Google study findings that assimilation occurred far less frequently than anticipated. For a total of 50 words that could have taken the assimilated prefix, two respondents used the assimilated *si-* six times and one respondent used it five times. At this point, to shorten the length of time required for survey participation and in hopes of acquiring more completed responses, the survey was revised so that that participants were only asked to provide grammaticality judgments, as seen in (21).

(21) Qualtrics® Survey: Version 2 Screenshot



Thirteen people completed the revised survey in the next three months. An independent samples *t*-test showed no significant differences between respondents' grammaticality ratings on version 1 and version 2 of the survey, with $p > 0.10$, indicating that they belonged to the same population. They were therefore grouped, bringing the total number of respondents up to 20.

Each of the 75 words from the noun list appeared in both the assimilated and unassimilated affixed forms, so participants provided grammaticality judgments on a total of 150 words which can be broken into four groups, as demonstrated in (22).

(22) Survey Word Types

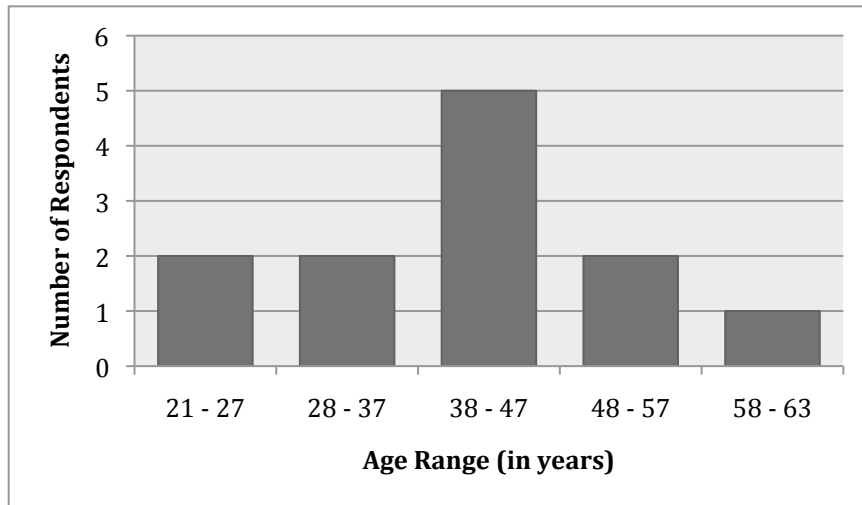
Word Type	Example	Nickname
filler affixed with <i>shi-</i>	shichaii, ' <i>my grandfather</i> '	SHI-FILLER
filler affixed with <i>si-</i>	*sichaii, ' <i>my grandfather</i> '	SI-FILLER
target affixed with <i>shi-</i>	shik'os, ' <i>my neck</i> '	SHI-TARGET
target affixed with <i>si-</i>	sik'os, ' <i>my neck</i> '	SI-TARGET

The SHI-FILLERS should be deemed grammatical, as there is no trigger for assimilation, while SI-FILLERS should be deemed ungrammatical for the same reason. Any variation that we see should be in the targets, such as *k'os*, '*neck*'. Because it contains an alveolar sibilant, the assimilated *sik'os* should be acceptable, and the results from the Google survey indicate that *shik'os* may be acceptable as well.

3.3 Results

Of the 20 participants, six were male, 13 were female, and one was undeclared. Only 12 participants—all female—reported their age. As shown in (23), they ranged from 21 to 63 years old with a mean age of 39.9 years.

(23) Age of Survey Respondents (10-year ranges)

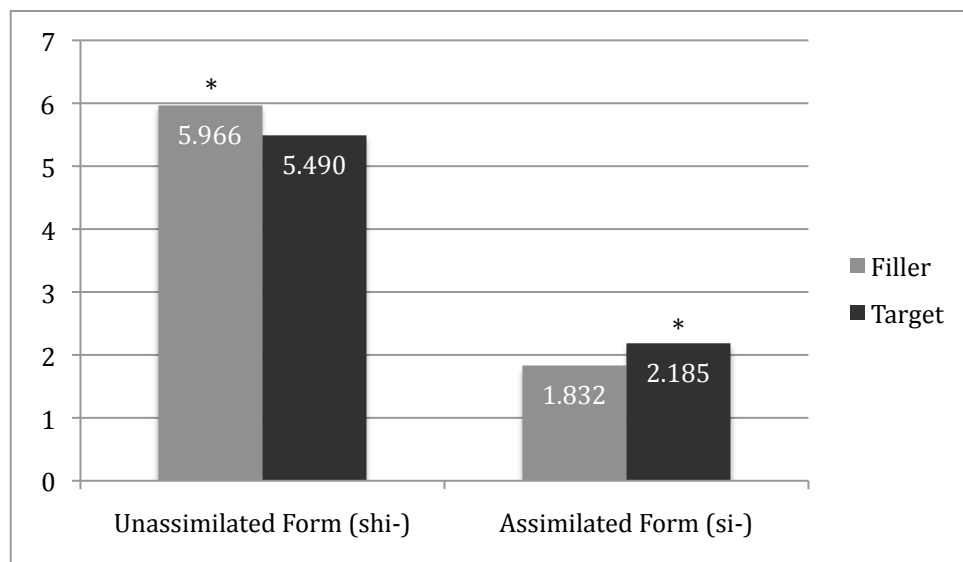


The grammaticality judgment scale ran from 1 to 7, with 1 signifying a terrible, ungrammatical word and 7 signifying a perfect, grammatical word. Thus the higher the score, the more grammatical the word. Paired samples *t* tests were conducted to determine whether mean grammaticality judgments varied significantly based on voicing, continuancy, adjacency, syllable position, and/or number of stem sibilants. Before reporting individual results, however, let us consider the broad picture painted by the survey results.

3.3.1 Targets vs. Fillers

To set the baseline, mean grammaticality judgment ratings were determined for the groups *shi-filler*, *si-filler*, *shi-target*, and *si-target*. A participant's mean grammaticality rating for *shi-filler*, for example, is calculated based on the individual grammaticality judgments given for each of the 25 fillers affixed with *shi-*, i.e. *shidaa'* ('my lip'), *shibid* ('my stomach'), et cetera. Mean grammaticality judgments for these four basic groups appear in (24).

(24) Mean Grammaticality: Targets vs. Fillers



It is immediately apparent when looking at (24) that the unassimilated *shi-* form is always preferred. This would be highly unexpected had the Google study

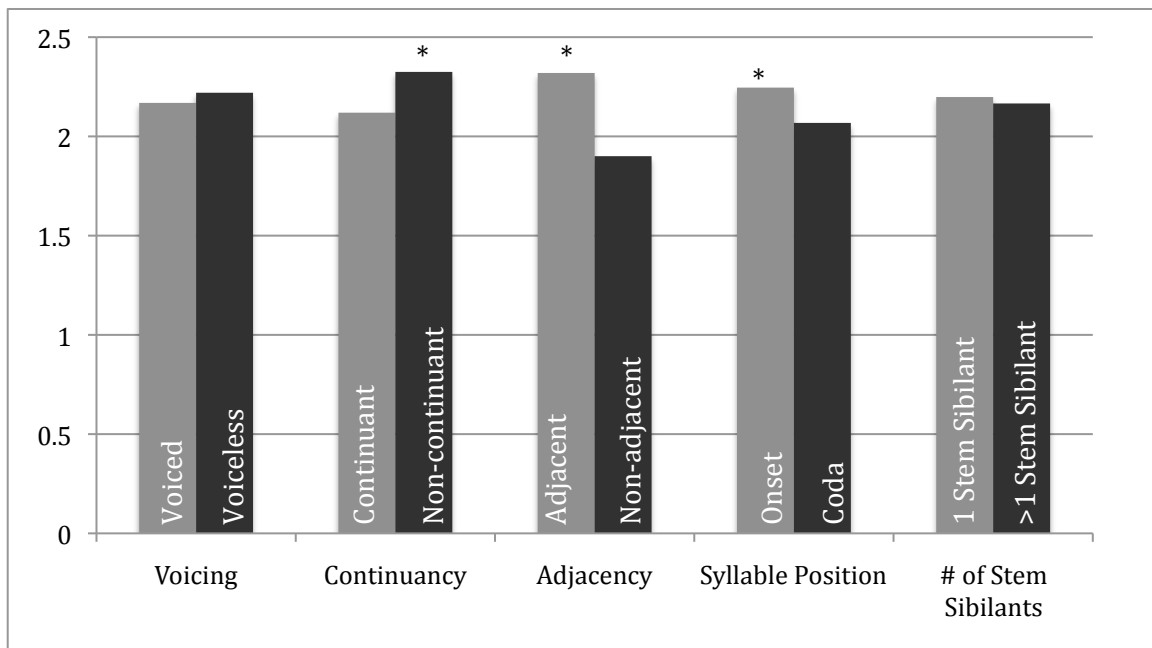
not prepared us for the fact that there might no longer be a mandatory assimilation environment, but our predictions here did not call for a mandatory environment. Rather, Prediction 3.1.1 stated that *si-* should be deemed less grammatical when affixed to fillers than to targets, and *shi-* should be deemed less grammatical when affixed to targets than to fillers. Based purely on a visual comparison of the means, this seems to be the case.

Paired-samples *t* tests were not viable in this instance because the distributions were skewed, and so the nonparametric Wilcoxon Signed Ranks Test was conducted to evaluate whether the mean grammaticality judgment for the *shi-target* group was significantly lower than that of the *shi-filler* group. The results indicated that targets affixed with *shi-* were deemed significantly less grammatical than fillers affixed with *shi-*, $z = -3.245$, $p < 0.001$; further, the effect size is large, $r = 0.5$. The same test was run to evaluate whether the mean grammaticality of *si-filler* was significantly lower than that of *si-target*, and again, results indicated that it was: $z = -2.25$, $p = 0.012$, $r = -0.44$.

More plainly, speakers judged targets to be significantly more grammatical than fillers when affixed with *si-* and fillers to be significantly more grammatical than targets when affixed with *shi-*, and both tests show a medium to large effect size. Having established that the difference between the mean grammaticality judgments of targets and fillers for both assimilated and unassimilated forms is statistically significant, we can now focus exclusively on the group composed of target words affixed with the assimilated *si-* prefix to determine whether variability

in grammaticality judgments can be traced to the factors of voicing, continuancy, adjacency, syllable position, and/or number of stem sibilants. The remaining sections, then, focus on the 50 target words affixed with the assimilated *si-*, i.e. *sik'os*, *sinaaltsoos*, et cetera. Mean grammaticality ratings for each of the groupings we will consider are seen in (25).

(25) Mean Grammaticality: Targets Affixed with *si-*, by Group



Recall that “2” is a very low rating; all forms affixed with the assimilated *si-* were deemed quite ungrammatical; in essence, the next sections investigate relative differences in the degree of “badness” of these forms based on the groupings shown above.

3.3.2 Voicing

A paired-samples *t* test was used to evaluate whether the mean grammaticality rating for forms affixed with *si-* was significantly higher for stems containing voiceless alveolar sibilants ($M = 2.2199, SD = 1.47570$) than for those containing voiced alveolar sibilants ($M = 2.1688, SD = 1.52155$). The results indicated that there was no significant difference in means, $t(19) = 1.079, p = 0.147$. In other words, the voicing specification of the stem sibilant did not significantly affect grammaticality judgments of assimilated forms.

3.3.3 Continuancy

A paired-samples *t* test was used to evaluate whether the mean grammaticality rating for forms affixed with *si-* was significantly different for stems containing [+continuant] alveolar sibilants ($M = 2.1194, SD = 1.34399$) than for those containing [-continuant] alveolar sibilants ($M = 2.3249, SD = 1.65472$). The test was significant but was not in the expected direction, $t(19) = -2.023, p = 0.029$. Further, there is a medium to large effect size, $r = 0.42$. The equation used to calculate effect size is shown in (26) (Field 2005, p. 294, from Rosnow & Rosenthal 2005, p. 328).

(26) r -value for Paired-Samples t Test

$$r = \sqrt{\frac{t^2}{t^2 + df}}$$

Manner of articulation of the stem sibilant significantly affected grammaticality judgments of assimilated forms, with stems containing noncontinuants receiving a significantly higher mean grammaticality rating when assimilated than stems that contained continuants. This aligns with the trend observed in Experiment 1, and motivates additional study of the salience of affricates as triggers.

3.3.4 Adjacency

A paired-samples t test was used to evaluate whether stems containing alveolar sibilants in adjacent syllables ($M = 2.3249$, $SD = 1.65472$) received higher grammaticality ratings when affixed with *si-* than stems containing alveolar sibilants in nonadjacent syllables ($M = 1.9003$, $SD = 1.24813$). The test was significant and in the expected direction, $t(19) = 1.807$, $p = 0.044$, with a medium effect size, $r = 0.38$.

3.3.5 Syllable Position

The mean grammaticality rating for stems containing alveolar sibilants in onset position ($M = 2.2457, SD = 1.51834$) was significantly higher than for those containing alveolar sibilants coda position ($M = 2.0679, SD = 1.36822$), with $t(19) = 2.263, p = 0.018$. The effect size was large, $r = 0.46$.

3.3.6 Number of Stem Sibilants

A paired-samples t test was used to evaluate whether forms affixed with *si-* received significantly higher grammaticality ratings if they contained multiple alveolar sibilants ($M = 2.1659, SD = 1.40187$) than if they contained containing a single alveolar sibilant ($M = 2.1983, SD = 1.46646$). The results indicated that there was no significant difference in means, $t(19) = -0.699, p = 0.247$.

3.4 Discussion

Several broad observations can be made about the data outlined above. The unassimilated *shi-* prefix is highly favored over the assimilated *si-* form in all contexts; words affixed with *si-* receive very low grammaticality ratings across the board, even when the stem sibilant is in a position such that it would formerly have been described as the mandatory assimilation environment. The implication seems clear; whether in data collected by surveying assimilation in online language use or

in the elicitation of grammaticality judgments from speakers, the mandatory environment for sibilant harmony no longer seems to exist—at least for the first person possessive morpheme. Harmony now appears to be optional in all environments.

One of our original questions dealt with how often harmony applies in optional environments. What does this mean, if all environments are now optional? Recall that in the Google results, the overall mean assimilation rate was 35% in both 2008 and 2010. Rates were highest for stems containing noncontinuants, for stems containing sibilants in adjacent syllables, and for stems containing multiple sibilants, and even in these groups assimilation occurred only between 40 and 50% of the time. Now we can add the survey data to the picture; when judging grammaticality, respondents simply did not like assimilated forms. Very few individuals rated assimilated forms as “good”—just two respondents had an overall average for *si-target* forms above 3.5, which was the Likert Scale midpoint. (One was 3.68; the other was 4.44.) For all other respondents, assimilated forms were never good; some were simply less bad than others. These results seem to suggest that harmony is not just optional all of the time, but is actually dispreferred.

That said, we can make some statements about which forms are less bad than others. Voicing specification of the stem sibilant did not lead to significant differences in mean grammaticality judgments; neither voiced nor voiceless sibilants in the stem triggered higher mean grammaticality ratings for assimilated forms. Number of stem sibilants did not matter, either; grammaticality judgments

did not differ significantly based on this factor. Recall that number of stem sibilants yielded no significant differences in the Google study, either; there was a slight but insignificant trend for stems with multiple sibilants to show higher rates of assimilation than stems with a single sibilant in Experiment 1. It has now been shown that this factor does not contribute significantly to gradient grammaticality judgments in Experiment 2, making it less tenable to suggest that the number of sibilants in the stem is salient with regards to establishing a trigger-target harmony relationship.

One way to consider the overall findings is to say that although harmony is dispreferred throughout, there are certain circumstances wherein speakers are more willing to tolerate harmony—or, better said, were willing to judge harmonized forms less harshly. In particular, significant differences in the mean grammaticality of assimilated forms were found when comparisons were based on manner of articulation, adjacency, and syllable position of the stem sibilants. Note that these are factors which came up repeatedly in the discussion on gradience found in Section 1.3.

Adjacency here is our measure of distance, which is a consistently important phonological factor. The assimilated forms of stems with alveolar sibilants in adjacent syllables were deemed significantly more grammatical than the assimilated forms of those with alveolar sibilants in nonadjacent syllables. This provides yet more evidence to support Sapir and Hoijer's original claim, even though we may have to tweak the framework; while they stated that harmony was mandatory when

sibilants were adjacent and optional when there was more distance, we can state that harmony is never mandatory for the first person possessive morpheme, but that the likelihood of harmony applying increases as distance decreases.

Additionally, as seen in the survey responses, the grammaticality of assimilated forms increases as distance decreases. These findings are in line with those reported by Martin (2005) regarding compound nouns in Navajo.

The manner of articulation division—i.e., whether the stem sibilant was a continuant or a noncontinuant—yielded significant results, allowing us to assess whether similarity or saliency played a more important role in establishing a correspondence relationship between the prefixal and stem sibilants. Recall that the similarity is widely acknowledged to be of great importance in consonant harmony systems; yet similarity cannot explain the assimilation pattern found here, for it would call for continuants to serve as more likely triggers for assimilation in Experiment I and for the assimilated forms of stems containing continuants to be deemed more grammatical than the assimilated forms of stems containing noncontinuant sibilants in Experiment II. The opposite was found, however; in Experiment II, stems containing noncontinuant sibilants received significantly higher grammaticality judgments when affixed with *si-* than those containing continuants, and although the difference was not statistically significant Experiment I found higher mean assimilation rates for stems with noncontinuant alveolar sibilants than for those with continuant alveolar sibilants. This supports a view of salience as

being more important than similarity, and of noncontinuants as better triggers for assimilation.

Finally, the assimilated forms of stems containing onset sibilants received significantly higher ratings than those containing coda sibilants. This is a distinction that did not come out in the Google study, but it is doubly expected. The prefixal sibilant is in onset position, so a similarity-based account predicts that stem sibilants in onset position will be stronger triggers. This finding is also consistent with a salience-based account, as onsets have been shown to be more salient than codas (Berkley 2000, Frisch 2000, Shattuck-Hufnagel 1985). Adding weight to those findings, it is also the case that for most categories of speech sounds, onsets are more perceptually salient for listeners than codas (Beckman 1998), and phonemic contrasts tend to be more often preserved in onset position than in coda position (Ohala and Kawasaki 1984). All of these point to syllable position as a salient phonological characteristic, with syllable onsets being more salient than syllable codas.

The extreme underrepresentation of assimilated forms in the written responses supplied by the seven participants would have been unexpected prior to Experiment I, but can now be seen to support its findings. Both Experiment I and Experiment II indicate that the mandatory assimilation environment no longer exists, and that harmony is applied less frequently than anticipated. No harmony is mandatory; all harmony is optional.

What can we hypothesize about the factors contributing to this shift away from consonant harmony? One possible influence may be school language classes; I have been told anecdotally that, at least in some high school Navajo language classes, assimilation is not being taught. Instead, students are taught that the first person possessive morpheme is *shi-*. This might explain the lack of harmony in second language learners, but presumably can't explain the lack of harmony in people who acquired the language in their homes as children. It is also true that English, which does not exhibit sibilant harmony, is ubiquitous in most parts of the United States. Future studies could investigate whether the loss of harmony may be related to encroachment by English.

Setting aside for the now questions about underlying factors, we return to a discussion of the survey results. The speakers who responded to this survey actively disliked harmonized forms, and the overall trend was to favor the unassimilated *shi-* at all times and in all situations. Grammaticality judgments for harmonized forms fell in the low end of the scale—centering around 2, which was a very ungrammatical rating—reflecting that harmony is dispreferred. These responses still exhibited the expected gradience, however; some phonological characteristics of the noun stems to which the prefix was affixed elicited harsher grammaticality judgments to assimilated forms, while assimilation was judged less harshly for stems containing noncontinuants, sibilants in onset position, and sibilants in adjacent syllables. One question which should be addressed in future work deals with the interaction of these three factors; the current set of data is not

large enough to support such an undertaking, but additional analysis may reveal significant interactions between these factors.

Experiments I and II used online, written language to investigate gradience in Navajo sibilant harmony. Now, we turn to an examination of the acoustic properties of spoken language to see whether the findings from the Google study and the grammaticality survey are reflected in Navajo speech. It was possible to investigate Navajo sibilant harmony online in Experiments I and II because assimilation has orthographic consequences in Navajo; it is important to ask, however, whether we will find similar patterns in spoken language. The third study presented herein was devised to address this question.

In Experiment III, speakers of Navajo who do not apply harmony in written language were recorded and the acoustic properties of the relevant fricatives were analyzed to determine whether the palatal fricative in the first person possessive morpheme is acoustically consistent in all environments, or whether it exhibits differences when affixed to stems that contain alveolar sibilants that are imperceptible to the listener.

4 Experiment III: An Acoustic Study of Navajo Sibilant (Non)assimilation

Experiment III seeks to determine whether sibilant harmony produces any measurable acoustic effects in the productions of Navajo users who do not perform

assimilation overtly. Recordings were made of three speakers who, impressionistically, pronounce the first person possessive morpheme as [ʃɪ-] at all times and in all environments; acoustic analysis of the prefixal sibilant was then performed to determine whether the presence of an alveolar sibilant in the stem triggers more [s]-like properties in the prefixal [ʃ].

This study was motivated by the findings of Experiments I and II. Sibilant harmony in Navajo has been consistently referred to as mandatory in some environments and optional in others (Hansson 2001, McDonough 2003, Sapir and Hoiyer 1967), but the results presented in this thesis suggest that there is no longer a mandatory harmony environment for the first person possessive morpheme in Navajo. The Google study indicated that the prefixal sibilant sometimes surfaces as *shi-* in online Navajo language use even when affixed to nouns with alveolar sibilants in word onset position, while the results from the grammaticality judgment survey suggested that harmony is not only optional but is actually dispreferred. Respondents consistently judged unassimilated *shi-* forms to be more grammatical than assimilated *si-* forms, even when the prefix attached to stems containing an alveolar sibilant. These studies made use of written language, however, in which there is no room for partial harmonization. It is possible that traces of harmony may be acoustically present in speaker productions, but that these traces simply are not reflected in written language use. McDonough (2003) touches on this point in *The Navajo Sound System*, wherein the following question is posed: “Is [harmony] a purely phonological alternation in which consonants have been outright replaced by

a harmonized reflex, or is it a more phonetically based and defined alternation in which there is a more gradient effect?" (49). If harmony does produce a gradient effect, acoustic analysis may serve to reveal it.

Three Navajo/English bilinguals were recorded producing a randomized word-list composed of nouns in the 1st-person possessed form. The digitized recordings were fed into PRAAT (Boersma & Weenink 2010), and waveforms and spectrograms were generated and used to measure the duration, spectral mean, and onset of frication energy for the word-initial fricative of each possessed noun, in addition to the onset of the second formant of the following vowel, in order to determine whether speakers who do not actively harmonize produce the palatal sibilant consistently at all times or whether it is acoustically altered by the presence of alveolar sibilants in the noun stem.

4.1 The Acoustic Properties of Navajo [s] and [ʃ]

If harmony triggers acoustically detectable effects, then we expect the morpheme-initial fricative in the 1st person possessive *shi-* to be more [s]-like when affixed to stems that contain alveolar sibilants (targets) than when affixed to stems that do not (fillers). Before we can determine what a more [s]-like [ʃ] looks like in Navajo, however, we need to determine the acoustic characteristics of these two sibilants in Navajo. While there are certain consistencies, fricatives also exhibit some crosslinguistic differences and so it is necessary to develop a language-specific

understanding of the properties of [s] and [ʃ]; to this end, the next pages pull information from a variety of sources in order to outline the acoustic properties of these sounds in Navajo. Mean acoustic measurements for [s] and [ʃ] were calculated for the three speakers included in this study. Findings related to English fricatives are referenced to some degree (Behrens and Blumstein 1988, Evers et al. 1998, Fox and Nissen 2005, Jongman et al. 2000, Wilde 1993), as is a crosslinguistic examination of voiceless fricatives in seven languages—six of which contain both [s] and [ʃ], and two of which belong to the same language family as Navajo (Gordon et al. 2002). Finally, the acoustic data for Navajo sibilants reported by McDonough (2003) is compared with the measurements obtained in the present study.

Detailed explanation of how the measures reported in Experiment III (fricative duration and spectral mean, onset of frication energy, and the F2 transition of the following vowel) were made appears in Section 4.3, Methods. For now, note that mean [s] measurements were calculated for each of the three participants, henceforth referred to as Female 1, Female 2, and Male 1. Means were calculated based on measurements from three repetitions each of approximately 14 tokens, a list of which appears in (27).⁵ Segments measured appeared in a variety of syllable positions and vowel contexts, and were consistent with the observation made by McDonough (2003) that Navajo fricatives—and sibilants in particular—are “strikingly” similar across word positions (p. 136).

⁵ The exact number varied somewhat between speakers because, as will be addressed in more detail shortly, speakers did not produce exactly the same lists of words; words produced varied somewhat based on vocabulary and dialectal differences.

(27) Tokens used for obtaining acoustic measurements of [s]

1. béeso	<i>money</i>	9. siis	<i>belt</i>
2. besistogi	<i>arrow head</i>	10. siil	<i>breath</i>
3. géeso	<i>cheese</i>	11. sis	<i>pocket</i>
4. k'is	<i>friend</i>	12. sodizin	<i>prayer</i>
5. k'os	<i>neck</i>	13. ta'azis	<i>pocket</i>
6. lamasani	<i>ring</i>	14. tsats'ósi	<i>needle</i>
7. mósí	<i>cat</i>	15. wos	<i>shoulder</i>
8. sin	<i>song</i>		

Note that some of the words listed in (27) differ from those found in Appendix B, due to speaker variation. Two of the three speakers recorded in this study produced sounds written as *z* in the Young and Morgan dictionary as [s]. Thus *ziiz*, 'belt,' was pronounced *siis*, and *zis*, 'pocket,' was pronounced *sis*.

Measurements for [ʃ] were always taken on the prefixal sibilant—i.e., on the initial sound in *shik'is*, 'my friend.' Mean acoustic measurements for [s] and [ʃ] are shown in (28), and discussion follows.

(28) Mean Acoustic Measurements for [s] and [ʃ]

	FEMALE1		FEMALE2		MALE1	
	[s]	[ʃ]	[s]	[ʃ]	[s]	[ʃ]
DURATION (in ms)	165*	110	151	155	150	132
SPECTRAL MEAN (in Hz)	8406*	5329	8711*	4788	5591*	3911
FRICATION ENERGY ONSET (in Hz)	2550*	1621	2848*	1770	1706*	1407
F2 TRANSITION (in Hz)	1961	1959	1864	1964	1607	1589

Independent samples *t* tests indicated that values for [s] marked with an asterisk were significantly different than the corresponding values for [ʃ], with $p < 0.001$. In other words, (28) indicates that the mean duration of [s] was significantly different than that of [ʃ] for Female 1, spectral mean and onset of frication energy differed significantly between [s] and [ʃ] for all three speakers, and F2 transition did not differ significantly based on the place of articulation of the preceding fricative for any of the speakers. Now let us consider these measures one by one.

With regards to duration, the results show that [s] is significantly longer than [ʃ] in Navajo for Female 1. This is inconsistent with the findings reported in McDonough (2003), who obtained durational and spectral measurements of Navajo consonants and vowels. McDonough's measurements of 14 speakers (10 female and four male) showed no statistically significant durational differences between any fricatives in Navajo; the median duration of [s] was 208.8 ms while that of [ʃ] was 208.6 ms (p. 76). This is consistent with crosslinguistic findings which show no durational difference between [s] and [ʃ] in English (Behrens and Blumstein 1988, Fox and Nissen 2005) and in Apache, Chickasaw, Montana Salish, and Toda (Gordon et al. 2002). Interestingly, Gordon et al. (2002) did find [s] to be significantly longer than [ʃ] in Scottish Gaelic; a significant durational difference was also found in Hupa, an Athabaskan language from California, but the Hupa data included speech from just one male and one female, and [s] was longer only for the female. Duration will be considered in Experiment III, but the data collected here and that reported by others suggest that Female 1's results are unusual, while the lack of significant

difference evidenced in Female 2 and Male 1's speech is more in keeping with the observed trend.

Spectral mean—also referred to in the literature as center of gravity—was found to be significantly higher for [s] than for [ʃ] for the three speakers recorded in this study. This is consistent with previous findings for English (Behrens and Blumstein 1988, Evers et al. 1998, Jongman et al. 2000); for Apache, Chickasaw, Scottish Gaelic, and Montana Salish (Gordon et al. 2002); and for Navajo (McDonough 2003). Center of gravity has also been reported to distinguish reliably between [s] and [ʃ] in the Tibeto-Burman language Anong, with the mean center of gravity of [s] being significantly higher than that of [ʃ] (Thurgood 2009). If we consider numerical values, Jongman et al. 2000 report means of 6133 Hz for English [s, z] and 4229 Hz for English [ʃ, ʒ] (p. 1257). For the Navajo data, McDonough reports a mean center of gravity for [s] of 6963 Hz and for [ʃ] of 3737 Hz (p. 134). Grouped means in the present study are 7569 Hz for [s] and 4676 Hz for [ʃ]; these are higher than McDonough's results, because the two female speakers have significantly higher measurements than the sole male participant. That said, the overall difference is similar, with the mean for [s] approximately 3000 Hz higher than that of [ʃ].

One standard observation that can be made about the spectral properties of [s] and [ʃ] is that the energy of [s] is generally higher, and that energy extends down into lower frequency ranges for [ʃ] (Kent and Read 2002). McDonough does not report measurements for the onset of frication energy per se, but does note that [s]

and [ʃ] are easily distinguished by “the lower edge of the energy bands” (p. 130-1). While this is not identical with the measurements taken in this study, it is consistent with the findings; the mean onset of frication energy is significantly higher for [s] than for [ʃ] for the speakers in this study; energy extends into lower frequencies for the palatal sibilant than for the alveolar sibilant.

Formant transitions of the following vowels are useful in distinguishing between fricatives in some languages—for example, they can be used to distinguish between [s] and [ʃ] in Anong (Thurgood 2009), and Wilde (1993) reports that F2 onset rises as the place of articulation moves farther back in the vocal tract for English fricatives. Jongman et al. (2000) confirms this finding, reporting a significantly lower mean F2 onset following [s, z] than following [ʃ, ʒ]. If this were true in Navajo then we would expect a higher mean F2 onset after [ʃ] than after [s], but this was not the case herein; no significant difference in the onset of the second formant of vowels following [s] and [ʃ] was found in the speech analyzed in this study.

Putting it all together, then, we can say the following: [s] has a higher spectral mean and a higher onset of frication energy than [ʃ] in Navajo. The formant transition of the following vowel does not differ based on the place of articulation of the sibilant. Duration is less straightforward; [s] is significantly longer for at least one speaker. Therefore, a more [s]-like [ʃ] should have a higher spectral mean and onset of frication energy for all speakers; durationally, a more [s]-like [ʃ] will be longer for Female 1. Duration will not be useful for Female 2 or Male 1.

We can now proceed with making predictions.

4.2 Predictions

If the target/filler distinction produces measurable effects in the prefixal sibilant, it should have a higher spectral mean and onset of frication energy before noun stems that contain alveolar sibilants than before those that do not. If we see differences within the targets—in other words, if factors like the continuancy or adjacency of stem sibilants contributes to harmony—then we expect to find more [s]-like measurements—i.e., higher spectral mean, and onset of frication energy—in the following patterns.

4.2.1 Voicing

The previous studies found neither a difference in assimilation rates nor a difference in grammaticality ratings based on the voicing specification of the stem sibilant; therefore we expect to see no significant differences in the acoustic properties of the prefixal sibilant based on the voicing of the stem sibilant.

4.2.2 Continuancy

In the grammaticality survey, speakers judged assimilated forms less harshly when they contained noncontinuants; this mirrored the trend observed in Experiment I, wherein stems containing noncontinuants showed numerically higher (though statistically insignificant) assimilation rates. Accordingly, noncontinuants are expected to be more salient and stems containing noncontinuants will trigger more [s]-like properties in the prefixal sibilant than those containing continuants.

4.2.3 Adjacency

Adjacency has been consistently important; sibilants in an adjacent syllable triggered more assimilation, and assimilated forms were judged less harshly when the sibilant was in an adjacent syllable. Thus we expect to find more [s]-like properties in the prefixal sibilant when the alveolar stem sibilant is in a syllable adjacent to the prefix than when it is in a nonadjacent syllable.

4.2.4 Syllable Position

We found no differences in assimilation rate based on the syllable position of the stem sibilant, but speakers judged assimilated forms of stems with onset sibilants less harshly than those of stems with coda sibilants. Thus we expect to see

more [s]-like properties in the prefixal fricative when it is affixed to stems containing onset sibilants than to those containing coda sibilants.

4.2.5 Number of Stem Sibilants

If we find differences based on the number of stem sibilants, we will see more [s]-like properties in the prefixal sibilant when it appears before stems with multiple sibilants than when it appears before stems that contain a single sibilant. Given the lack of significance of this factor in the previous experiments, however, no significant differences are expected.

4.3 Methods

4.3.1 Subjects

Stimuli were produced by three bilingual speakers of Navajo and English, one male (Male 1) and two female (Female 1 and Female 2). Prior to beginning the recording, each participant was asked to complete a questionnaire designed to gather demographic information and details about their Navajo language use (see Appendix C). Speakers are in their late twenties, and grew up in the northeast corner of the Navajo Nation in the northeast corner of the state of Arizona. All three spoke Navajo a lot in the home while growing up; at the time of the recordings, Female 1 reported using Navajo language a little bit with her parents and her

siblings and/or friends, while Male 1 and Female 2 reported speaking Navajo a lot with their parents and grandparents and a little bit with their siblings and/or friends.

4.3.2 Stimuli

The stimuli consisted of a total of 89 Navajo nouns; 62 were targets containing one or more alveolar sibilants, while the other 27 were fillers. In addition to the 75 nouns from the online survey—which can be found in Appendix B—the list included the 14 nouns found in (29).

(29) Acoustic Study Noun List - Additions to Appendix B

1. béeso	<i>money</i>	8. jéí	<i>heart</i>
2. chidí	<i>car</i>	9. kááz	<i>gland, tonsil</i>
3. dzi'izí	<i>bike</i>	10. látsíní	<i>bracelet</i>
4. dzi'izítso	<i>motorcycle</i>	11. máazo	<i>marble</i>
5. 'éénééz	<i>overcoat</i>	12. mósí	<i>cat</i>
6. 'éétsoh	<i>coat</i>	13. tsats'ósí	<i>needle</i>
7. géeso	<i>cheese</i>	14. tsásk'eh	<i>bed</i>

Each noun was repeated three times, resulting in a randomized list of 267 tokens. The researcher presented stimuli to participants verbally in English, as illustrated in (30).

(30) Elicitation of Stimuli

Researcher: How do you say ‘my cat’ in Navajo?

Participant: *shimósí*

Some of the words on the list—such as *doolghas*, ‘scallop,’ or *t’iis*, ‘Cottonwood tree’— are very uncommon, geographically specific, or both, meaning that some words were unknown to one or more of the speakers. Participants were instructed to skip words they did not know, and in all instances this resulted in a reduced number of total usable tokens. In addition, participants occasionally produced a different word than the researcher intended to elicit. No attempt was made by the researcher to elicit the intended word, but occasionally the participant inadvertently supplied the intended word anyway, as demonstrated in (31).

(31) Elicitation of ‘my cat’

Researcher: How do you say ‘my cat’ in Navajo? (desired response: *shimósí*)

Participant: *Shigidi*—well, some people would say *mósí*, *shimósí*, but I say *gidi*.

A final explanatory comment that should be made is that, in some instances a speaker’s pronunciations varied in a way that affected categorization of the targets. For example, one speaker consistently pronounced the word for ‘prayer’ *tsodizin*, with an initial noncontinuant, rather than *sodizin*, as it appeared in the wordlist. For this speaker, then, the *tsodizin* went into the noncontinuant category, while for the

other speakers, who pronounced *sodizin*, it went into the continuant category; as a result, the specific members of a category varied from speaker to speaker. Results will be discussed individually, by person, and will include a report of the total number of tokens each individual produced.

4.3.3 Recording

Speakers were recorded onto a flash disc using a Marantz Portable Solid State Recorder at a sampling rate of 22 kHz in the anechoic chamber at the Lawrence, KS campus of the University of Kansas.

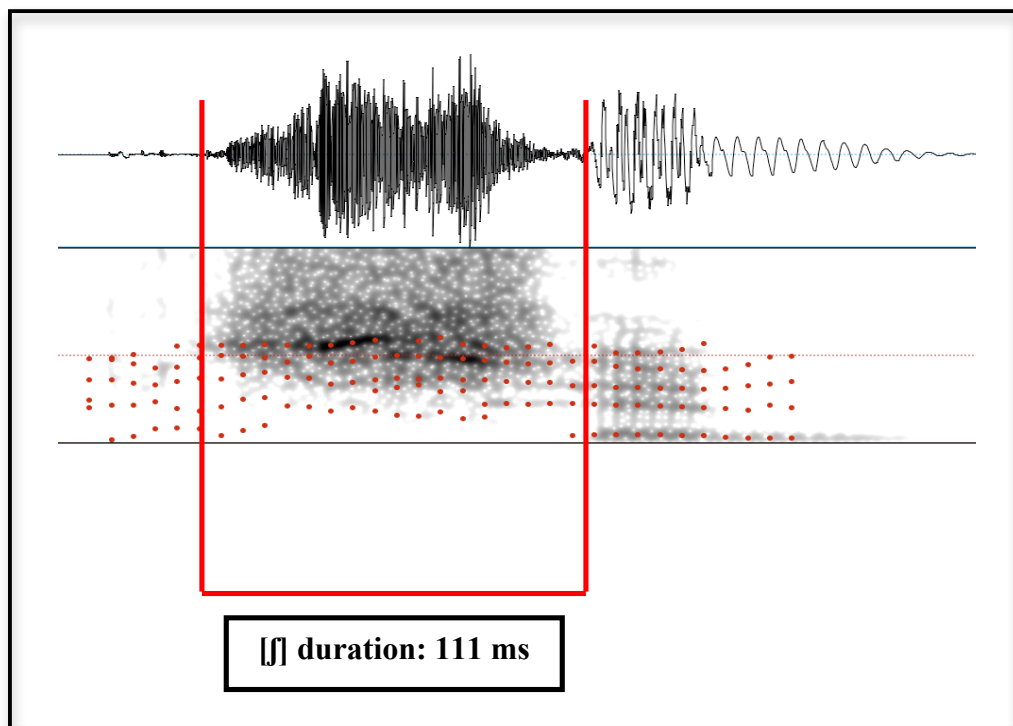
4.3.4 Acoustic Analysis

The digitized recordings were imported into PRAAT, freeware used for acoustic analysis. PRAAT allows simultaneous examination of the waveform and (wide-band) spectrogram of each token. The acoustic measurements taken included duration, spectral mean, onset of frication energy, and onset of the F2 of the following vowel. At the risk of being redundant, bear in mind as we move into discussion of these measures that the segment measured in each word was the fricative in the 1st-person possessive /ʃɪ-/. Thus for the token referenced in (31)—*shimósí*, ‘my cat’—measurements were taken on the word-initial [ʃ].

4.3.4.1 Duration

Duration of the fricative was measured from the jump in the waveform associated with the onset of noise—which coincides with the appearance of the band of high-frequency energy associated with the sibilant that is clearly visible in the spectrogram—to the beginning of the periodicity associated with the following vowel. An example appears in (32).

(32) Duration of [ʃ] in shibéeso, ‘my money’



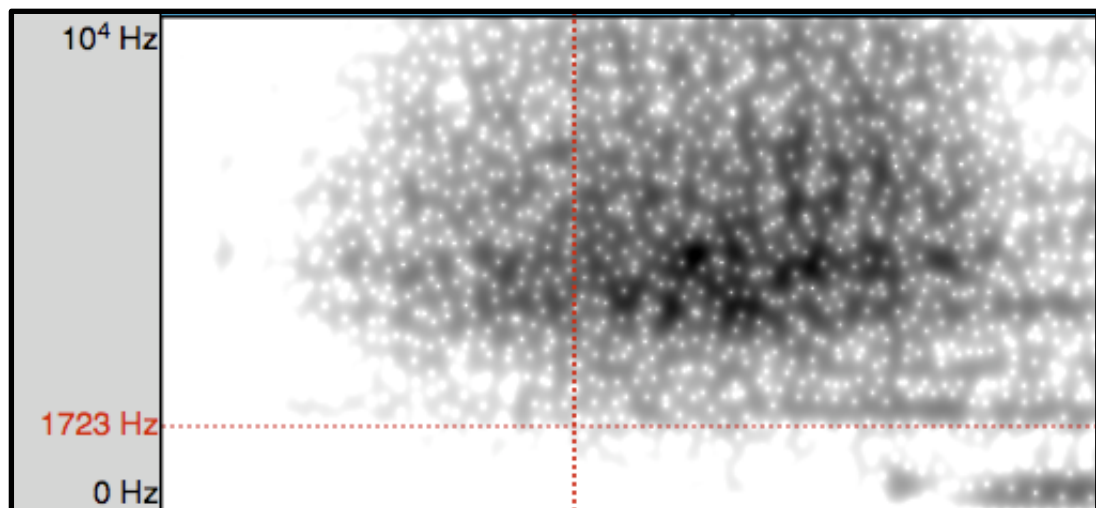
4.3.4.2 Spectral Mean

A 40 millisecond window from the exact center of the fricative was used to measure spectral mean. In the example shown above, the center of the fricative was located at 55.5 ms from the onset of noise, so the portion selected ran from 35.5 ms to 75.5 ms from noise onset. Next, PRAAT was used to create a spectral slice, and to calculate the center of gravity—or the spectral mean—from the spectrum.

4.3.4.3 Onset of Frication Energy

The spectrogram generated by PRAAT was used to determine the onset of frication energy for each sibilant. As shown in (33), the band of high frequency energy associated with the prefixal sibilant in *shizid*, ‘my liver,’ is consistently present starting at 1723 Hz.

(33) Onset of Frication Energy for [ʃ] in shizid, ‘my liver’



4.3.4.4 F2 Transition

The F2 measurement for the vowel portion of the morpheme /ʃɪ-/ was taken by determining the center of the dark band of energy associated with the second formant. This measurement was taken at the beginning of the vowel portion, as indicated by the onset of clear periodicity in the waveform.

4.4 Results

Participant data will be reported individually, in large part, essentially resulting in three mini case studies, but overall averages are presented in (34).⁶ Recall that FILLER measurements refer to those taken from the prefixal sibilant in the possessed form of the filler words—words containing no alveolar sibilants, such as *shichaii*, ‘my maternal grandfather.’ TARGET measurements are taken from the [ʃ] in the possessed form of words that contained alveolar sibilants, such as *shimósi*, ‘my cat.’

⁶ Speaker data is combined and grouped analysis is presented in Section 4.4.4.

(34) Mean Acoustic Measurements for Female 1, Female 2, and Male 1

	FEMALE 1		FEMALE 2		MALE 1	
	Filler	Target	Filler	Target	Filler	Target
DURATION (in ms)	110	107	155	147	132	134
SPECTRAL MEAN (in Hz)	5329	5208	4788	4894	3911	3949
FRICATION ENERGY ONSET (in Hz)	1621	1669	1770	1875	1407	1443
F2 TRANSITION (in Hz)	1959	1962	1964	1977	1589	1600

The important observations to make when looking at the table in (34) include the following. For an anterior sibilant in the root to trigger [s]-like properties in the prefixal fricatives, it must be the case that [s] and [ʃ] do in fact differ significantly along the parameter in question. As previously stated, F2 transition into the following vowel did not differ significantly based on the place of articulation of the preceding sibilant; this measurement will therefore be excluded from the rest of the analysis. However, since [s] has a significantly higher spectral mean and higher onset of frication energy than [ʃ] for all speakers, and has a longer duration than [ʃ] for at least one speaker, these measures will be analyzed to determine whether the palatal sibilant is more [s]-like before targets than it is before fillers.

Several general observations can be made before moving into the reporting of individual participant data. In particular, for two of the three participants discussed herein the adjacency and continuancy specification of the root sibilant yielded differences that approached significance in the acoustic properties of the prefixal sibilant. Details will be provided in the following sections, but it is worth

pointing out that these are the factors which have come to the forefront repeatedly in this thesis; in the Google study, the adjacency specification of the stem sibilant yielded significantly different rates of assimilation, and while the differences in assimilation rates were not significant, stems containing noncontinuants showed numerically higher mean assimilation rates than those containing continuants in both 2008 and 2010, supporting a view of noncontinuants as salient. In the online survey, stems containing alveolar sibilants in adjacent syllables and stems containing noncontinuants were judged significantly less harshly than those containing nonadjacent sibilants and continuants. The consistency with which these two factors are shown to be relevant will be discussed in more detail in the following sections.

For all tests conducted in this study, the significance level was set at 0.05 and the Levene statistic was used to test the homogeneity of variance for all samples. A series of pairwise comparisons was run on each set of data, in addition to the overall ANOVA; the number of tests conducted increased the risk of a Type I error, and so the *post hoc* procedure utilized was the conservative Bonferroni test. In essence, this meant running the risk of missing a genuine effect in order to decrease the risk of calling something significant when it was not (Field 2005, p. 340).

While commentary on the results will be saved, in large part, for Section 5, it should be stated before moving ahead that very few tests resulted in significant results; it was most often the case that results approached significance, with *p*-values falling in the 0.06 – 0.08 range. These results will be reported nonetheless, as

they may serve to inform the direction taken in future studies—studies that would benefit from more participants and a greater number of tokens. Now, for the reporting of individual results.

4.4.1 Female 1

Female 1 produced a total of 51 words, 30 targets and 21 fillers. One-way analyses of variance were conducted to assess the relationship between stem sibilants and the acoustic properties of the sibilant in the prefix /ʃr-/. The first test conducted simply compared measurements of the prefixal [ʃ] preceding targets, i.e. Navajo stems that contained alveolar sibilants, to those of the prefixal [ʃ] preceding fillers, i.e. stems that contained no alveolar sibilants. As seen in (35), no significant differences were found.

(35) Female 1: Target vs. Filler ANOVAs

	<i>M</i>		<i>SD</i>		<i>F</i> (1, 49)	<i>p</i>
	Target	Filler	Target	Filler		
DURATION (in ms)	106.5	109.6	12.29	19.43	0.48	0.492
SPECTRAL MEAN (in Hz)	5208.07	5329.29	414.96	349.35	0.41	0.525
FRICATION ENERGY ONSET (in Hz)	1669.4	1620.86	288.45	231.93	1.20	0.279

In order to determine whether differences would emerge when the target group was divided according to the features of interest—voicing, continuancy, adjacency, syllable position, and number of stem sibilants—another series of ANOVAs were conducted. In these, the independent variable included three levels: fillers, in which the stems included no alveolar sibilants, as well as each specification for the feature being assessed. Thus when conducting an ANOVA to assess the effect of the voicing specification of the stem sibilant, for example, the three levels included fillers, stems that contained voiced alveolar sibilants (henceforth voiced stems), and stems that contained voiceless alveolar sibilants (henceforth voiceless stems). The dependent variables included the previously mentioned acoustic properties of the prefixal sibilant: duration, spectral mean, and onset of frication energy.

As seen in (36), neither the voicing specification nor the syllable position of the stem sibilant yielded any significant differences in mean acoustic values in Female 1’s speech; the same was true for the number of alveolar stem sibilants.

(36) Female 1: Overall ANOVAs

	Voicing		Syllable Position		# of Stem Sibilants	
	<i>F</i> (2, 45)	<i>p</i>	<i>F</i> (2, 43)	<i>p</i>	<i>F</i> (2, 47)	<i>p</i>
DURATION	.006	.994	.152	.859	.026	.974
SPECTRAL MEAN	.583	.562	.508	.605	.598	.554
FRICATION ENERGY ONSET	.174	.841	.289	.750	1.756	.184

Note that stems which contained multiple sibilants with conflicting values of one of the features of interest were excluded from that group; for example, although Female 1 produced a total of 51 words, several—such as *zis*, ‘bag’—contained both a voiced and a voiceless alveolar sibilant. This word was therefore excluded from the analysis when data was divided according to the voicing specification of the stem sibilant. Note that *zis* also contains both an onset and a coda sibilant; accordingly, it was also excluded from the syllable position analysis.

The important thing to note in (36) is that, as indicated by the *p*-values, there are no significant differences in duration, spectral mean, or the onset of frication energy of the prefixal sibilant based on the voicing specification, the syllable position, or the number of alveolar stem sibilants. Unsurprisingly, post hoc analyses conducted to evaluate pairwise differences between means yielded no significant results. Next we turn to a discussion of the effects of the continuancy and adjacency specifications of stem sibilants.

4.4.1.1 Continuancy

A one-way analysis of variance was conducted to evaluate the relationship between the continuancy specification of the alveolar sibilants in Navajo noun stems and the acoustic measurements taken on the sibilant in the first person possessive morpheme *shi-*. The independent variable—continuancy of stem sibilant—included

three levels: fillers; stems which contained continuant alveolar sibilants (henceforth continuant stems); and stems which contained noncontinuant alveolar sibilants (henceforth noncontinuant stems). An illustrative example appears in (37).

(37) Example of Filler, Continuant, and Noncontinuant Stems

Stem Type	Sample Word
Filler	shidaa' <i>my lip</i>
Continuant Stem	shik'is <i>my friend</i>
Noncontinuant Stem	shitsili <i>my younger brother</i>

The dependent variables were the duration, spectral mean, and frication onset energy in the prefixal sibilant. The ANOVA approached significance for spectral mean, $F(2, 42) = 2.564, p = 0.089^7$, and so a post hoc procedure was conducted to evaluate pairwise differences among the means. Recall that the relevant prediction stated that for the target nouns—those containing alveolar sibilants—stems containing noncontinuants would trigger more [s]-like properties in the prefixal [ʃ] than stems containing continuants; with regards to spectral mean, we would therefore expect to see a higher average spectral mean for the noncontinuant stems than for the continuant stems. However, although the spectral mean of the prefixal sibilant was higher before noncontinuant stems ($M = 5357.62$ Hz, $SD = 519.28$ Hz) than before continuant stems ($M = 5046.42$ Hz, $SD = 268.59$ Hz), the Bonferroni test indicated that the difference was not significant, with $p = 0.154$.

⁷ The continuancy test results for duration were $F(2, 42) = 0.098, p = 0.907$; for onset of frication energy, $F(2, 42) = 0.315, p = 0.731$.

Unexpectedly, the spectral mean of the prefixal sibilant before filler stems ($M = 5329.29$ Hz, $SD = 349.35$ Hz) was closest to that of noncontinuant stems. In short, then, the sibilant portion of the prefix had a numerically lower spectral mean when attached to continuant stems than when attached to fillers or noncontinuant stems, but the difference did not attain significance.

4.4.1.2 Adjacency

A one-way analysis of variance was also conducted to assess the relationship between the adjacency of the alveolar sibilants in Navajo noun stems and the acoustic measurements taken on the sibilant in the first person possessive morpheme *shi-*. The independent variable—whether or not the stem sibilant appeared in a syllable adjacent to the prefix—included three levels: fillers; stems which contained alveolar sibilants in adjacent syllables (henceforth adjacent stems); and stems which contained alveolar sibilants in syllables not adjacent to the prefix (henceforth nonadjacent stems). Examples appear in (38).

(38) Example of Filler, Adjacent, and Nonadjacent Stems

Stem Type	Sample Word
Filler	shidaa' <i>my lip</i>
Adjacent Stem	shitsoosk'id <i>my thigh</i>
Nonadjacent Stem	shinaaltsoos <i>my book</i>

The dependent variables were the change in duration, spectral mean, and frication onset energy in the prefixal sibilant. The ANOVA approached significance for duration, $F(2, 41) = 2.834, p = 0.07^8$, and so follow-up tests were conducted to evaluate pairwise differences among the means. Recall that the relevant prediction stated that for the target nouns—those containing alveolar sibilants—stems containing sibilants in adjacent syllables would trigger more [s]-like properties in the prefixal [ʃ] than stems containing sibilants in nonadjacent syllables; we would therefore expect to see a longer mean duration for the adjacent stems than for the nonadjacent stems. The Bonferroni post hoc procedure indicated that the difference between the mean duration of the prefixal sibilant for adjacent stems ($M = 102.72$ ms, $SD = 10.24$ ms) and nonadjacent stems ($M = 115.67$ ms, $SD = 9.91$ ms) approached significance, with $p = 0.067$. There was no significant difference between the mean duration of [ʃ] before fillers ($M = 106.4$ ms, $SD = 12.97$ ms) and before either adjacent or nonadjacent stems.

Although the adjacency specification of the stem sibilant did not significantly alter the mean duration of the prefixal sibilant, what is surprising once again is that the minimal differences in means runs counter to that we might have expected, with the prefixal sibilant showing a longer mean duration when affixed to nonadjacent stems than to either adjacent stems or fillers.

Before moving on to Female 2's results, let us briefly summarize the findings related to Female 1. Acoustically, Female 1's sibilants reflect her written and verbal

⁸ The Adjacency test values for spectral mean were $F(2, 41) = 1.141, p = 0.329$; for frication energy onset, $F(2, 41) = 0.670, p = 0.517$.

behavior, at least with regards to the measurements taken in this study. She does not perform sibilant harmony in writing, and there is no evidence of assimilation when listening to her with the naked ear. We can now add that the prefixal sibilant shows no signs of being acoustically more [s]-like when preceding a stem that contains a trigger for assimilation—i.e., an alveolar sibilant—in terms of duration, spectral mean, and onset of frication energy. Whether the test results that approached significance might be strengthened by a larger body of data remains an open question. If the answer to that question is yes, then the data reported above suggests that the adjacency and the continuancy specification of the stem sibilant may continue to be of interest.

4.4.2 Female 2

Female 2 produced a total of 82 words—57 targets and 25 fillers—and unlike Female 1, some differences emerged in the initial target vs. filler analysis of variance, the results of which are found in (39).

(39) Female 2: Target vs. Filler ANOVAs

	<i>M</i>		<i>SD</i>		<i>F</i> (1, 49)	<i>p</i>
	Target	Filler	Target	Filler		
DURATION (in ms)	146.54	155	21.36	19.02	2.91	0.092
SPECTRAL MEAN (in Hz)	4893.86	4787.96	343.67	365.80	1.59	0.210
FRICATION ENERGY ONSET (in Hz)	1875.21	1770.12	184.03	168.25	5.96	0.017

While neither the mean duration nor the average spectral mean differs significantly between targets and fillers, the onset of frication energy is significantly higher for targets than for fillers.

In the next phase of tests, results indicated that the continuancy, adjacency, syllable position, and number of alveolar sibilant(s) did not yield significant differences in mean acoustic values, as demonstrated by the *F*- and *p*- values listed in (40).

(40) Female 2: Overall ANOVAs

	Continuancy		Adjacency		Syllable Position		# of Stem Sibilants	
	<i>F</i> (2, 68)	<i>p</i>	<i>F</i> (2, 70)	<i>p</i>	<i>F</i> (2, 43)	<i>p</i>	<i>F</i> (2, 47)	<i>p</i>
DURATION	2.158	0.123	1.892	0.158	1.760	0.180	1.485	0.233
SPECTRAL MEAN	1.383	0.258	.968	0.385	1.282	0.285	0.845	0.434
FRICATION ENERGY ONSET	2.459	0.093	2.786	0.068	2.708	0.074	2.947	0.058

Recall that in the target vs. filler ANOVA, significance was reached only for onset of frication energy. Note that although there are no significant findings at the 0.05 level, the test results approached significance with regards to onset of frication energy for all of the independent variables above. Bonferroni post hoc procedures were conducted but did not return any significant results.

Let us turn to the one remaining independent variable, then.

4.4.2.1 Voicing

The voicing specification of the stem sibilant did not yield any significant differences in assimilation rates in the Google study, nor did it yield significantly different grammaticality judgment ratings in the survey, so the prediction in this study was that no differences would be found based on voicing. However, this was not the case. A one-way analysis of variance was conducted to evaluate the relationship between the voicing specification of the alveolar sibilants in Navajo noun stems and the acoustic measurements taken on the sibilant in the first person possessive morpheme *shi-*. The independent variable—voicing of stem sibilant— included three levels: fillers, voiced stems (which contained voiced alveolar sibilants), and voiceless stems (which contained voiceless alveolar sibilants). Examples of these categories appear in (41).

(41) Example of Filler, Voiced, and Voiceless Stems

Stem Type	Sample Word
Filler	shidaa' <i>my lip</i>
Voiced Stem	shikaz <i>my cane</i>
Voiceless Stem	shik'os <i>my neck</i>

The dependent variables were the change in duration, spectral mean, and frication onset energy in the prefixal sibilant. The ANOVA was not significant for

duration ($F(2, 69) = 1.948, p = 0.15$) or for spectral mean ($F(2, 69) = 0.756, p = 0.473$), but because it was significant for onset of frication energy ($F(2, 69) = 3.90, p = 0.025$) a post hoc procedure was conducted to evaluate pairwise differences among the means. The Bonferroni test indicated that the difference in mean onset of frication energy between the voiced stem ($M = 1912.85 \text{ Hz}, SD = 164.00 \text{ Hz}$) and voiceless stem ($M = 1877.85 \text{ Hz}, SD = 181.72 \text{ Hz}$) groups was not significant. The difference between the filler mean ($M = 1770.12 \text{ Hz}, SD = 168.25 \text{ Hz}$) and the voiceless mean, however, approached significance, with $p = 0.065$; the difference between filler and voiced stem means also approached significance, with $p = 0.058$. In short, then, the sibilant portion of the prefix had a higher onset of frication energy when attached to target stems than when attached to fillers; this difference was in the right direction, was significant in the overall ANOVA, and approached significance in the post hoc pairwise comparisons.

This is the only result wherein the voicing specification of the stem sibilant came into play, and so the results bear some consideration. While the overall filler vs. target ANOVA indicated significance, pairwise comparisons show that the voiced and voiceless stem means do not differ significantly from one another. In other words, the voicing specification of the stem sibilant does not significantly alter the onset of frication of the prefixal sibilant; it is merely the presence of an alveolar in the stem that triggers a change. As previously stated, this is not surprising given the overall status of voicing in the Navajo phonetic inventory—it is not of particular import, and voicing is a distinctive feature in Navajo only for fricatives.

4.4.3 Male 1

Male 1 produced 24 targets and 28 fillers, for a total of 52 words. As shown in (42), no significant differences in acoustic measures were found in the initial target vs. filler analysis of variance.

(42) Male 1: Target vs. Filler ANOVAs

	<i>M</i>		<i>SD</i>		<i>F</i> (1, 49)	<i>p</i>
	Target	Filler	Target	Filler		
DURATION (in ms)	134.32	132.10	26.09	13.52	0.16	0.690
SPECTRAL MEAN (in Hz)	3949.84	3910.65	271.02	260.14	0.30	0.586
FRICATION ENERGY ONSET (in Hz)	1443.15	1406.58	185.62	153.96	0.6	0.442

In the next set of ANOVAs, wherein the target group was divided according to the independent variables of alveolar stem sibilant voicing, continuancy, adjacency, syllable position, and number, results indicated that continuancy and adjacency yielded significant differences in mean acoustic values. These results are presented in sections 4.4.3.1 and 4.4.3.2. *F*- and *p*- values for the three variables that did not yield significance appear in (43).

(43) Male 1: Overall ANOVAs

	Voicing		Syllable Position		# of Stem Sibilants	
	<i>F</i> (2, 45)	<i>p</i>	<i>F</i> (2, 43)	<i>p</i>	<i>F</i> (2, 47)	<i>p</i>
DURATION	.008	.992	.324	.725	.594	.556
SPECTRAL MEAN	2.327	.109	.082	.921	.148	.863
FRICATION ENERGY ONSET	2.211	.121	2.021	.146	.824	.445

4.4.3.1 Continuancy

A one-way analysis of variance was conducted to evaluate the relationship between the continuancy specification of the alveolar stem sibilants and the acoustic measurements taken on the prefixal sibilant in the first person possessive morpheme *shi-*. The independent variable—continuancy of stem sibilant—included three levels: fillers, continuant stems, and noncontinuant stems. Dependent variables included the change in duration, spectral mean, and frication onset energy of the prefixal sibilant.

Recall that the relevant prediction stated that for the target nouns—those containing alveolar sibilants—stems containing noncontinuants would trigger more [s]-like properties in the prefixal [ʃ] than stems containing continuants; we would therefore expect to see a longer mean duration for the noncontinuant stems than for the continuant stems. This was not, however, the case: the mean duration of the prefixal sibilant was longer before continuant stems ($M = 146.24$ ms, $SD = 30.86$) than before noncontinuant stems ($M = 123.33$ ms, $SD = 10.36$). Unexpectedly, the

duration of the sibilant before filler stems, $M = 132.10$ ms, $SD = 13.52$, fell in the middle. The overall ANOVA indicated a significant between groups difference, $F(2, 42) = 3.454$, $p = 0.041$, but because the variances were not homogenous the nonparametric Kruskal-Wallis test was employed. This test indicated that the differences in mean duration were not significant, with $H = 4.33^9$ and $p = 0.115$. In short, then, the sibilant portion of the prefix had the longest duration when attached to continuant stems and the shortest duration when attached to noncontinuant stems, but ultimately the differences were not significant.

4.4.3.2 Adjacency

A one-way analysis of variance was also conducted to assess the relationship between the adjacency of the alveolar sibilants in Navajo noun stems and the acoustic measurements taken on the sibilant in the first person possessive morpheme *shi-*. The independent variable—whether or not the stem sibilant appeared in a syllable adjacent to the prefix—included three levels: fillers, adjacent stems, and nonadjacent stems. The dependent variables were the change in duration, spectral mean, and frication onset energy in the prefixal sibilant. The test was not significant for duration ($F(2, 43) = 0.412$, $p = 0.665$) or for onset of frication energy ($F(2, 43) = 1.622$, $p = 0.209$), but it was significant for spectral mean, $F(2, 43) = 3.821$, $p = 0.029$. Therefore, follow-up tests were conducted to evaluate pairwise differences among the means.

⁹ The H value found in the Kruskal-Wallis test is often equated with the χ^2 value.

Recall that the relevant prediction stated that for the target nouns, stems containing sibilants in adjacent syllables would trigger more [s]-like properties—in this instance, a higher spectral mean—in the prefixal [ʃ] than stems containing sibilants in nonadjacent syllables.

The Bonferroni post hoc procedure indicated that the average spectral mean of the prefixal sibilant for adjacent stems ($M = 4097.38$ Hz, $SD = 291.14$ Hz) was significantly higher than that of nonadjacent stems ($M = 3779.76$ Hz, $SD = 168.23$ Hz), with $p = 0.031$. There was no significant difference between the spectral mean of [ʃ] before fillers ($M = 3910.65$ Hz, $SD = 260.14$ Hz) and before either adjacent stems ($p = 0.138$) or nonadjacent stems ($p = 0.624$).

4.4.4 Grouped Analysis

Grouped analysis was performed to determine whether the trends evidenced in the individual data would emerge as significant. To do this, tokens produced identically by all three participants were identified—speakers produced identical terms for 16 targets and 17 fillers, for a total of 33 tokens. Speaker measurements for each token were then averaged—the duration of the prefixal fricative when affixed to *béeso*, ‘money,’ for example, was 143 ms, 100.67 ms, and 101 ms for the individual speakers, resulting in a grouped average duration of 114.89 ms. Averages were calculated for the duration, spectral mean, onset of frication energy, and F2 transition into the following vowel for each of the 33 tokens produced identically, and grouped analysis statistics were carried out using these averages.

A target vs. filler analysis of variance indicated that only the mean onset of frication energy of the prefixal sibilant was significantly higher before targets ($M = 1670$ Hz, $SD = 79$ Hz) than before fillers ($M = 1587$ Hz, $SD = 116$ Hz), with $F(2, 31) = 5.66$, $p = 0.024$. No significant target-filler differences were found for duration or spectral mean.

In the individual data, filler means were sometimes the midpoint; for example, in Male 1's data the spectral mean of the prefixal sibilant was highest before adjacent stems, lowest before nonadjacent stems, and midway between the two before filler stems. Independent samples t -tests were therefore conducted between the target variables, and significant differences in spectral mean were found based on the continuancy specification and syllable position of the stem sibilants.

The prefixal [ʃ] had a higher spectral mean before stems containing noncontinuants ($N = 6$; $M = 4813$ Hz, $SD = 205$ Hz) than before those containing continuants ($N = 7$; $M = 4588$ Hz, $SD = 143$ Hz). The test was significant, with $t(11) = 2.12$, $p = 0.029$.

Spectral mean was also higher before stems containing alveolar sibilants in onset position ($N = 11$; $M = 4780$ Hz, $SD = 195$ Hz) than before those containing alveolar sibilants in coda position ($N = 3$; $M = 4525$ Hz, $SD = 120$ Hz). Despite the difference in sample sizes, assumptions of normalcy were met and the test indicated significance with $t(12) = 1.91$ and $p = 0.044$.

4.5 Discussion

The results of this study present an interesting picture. Impressionistically, no effects of consonant harmony are present in their spoken language. Having investigated several acoustic measures of the prefixal sibilant in potential harmony environments, we can now state that for one of the speakers, this is truly the case. Female 1 does not perform sibilant harmony on the first person possessive morpheme; there are no significant differences in the duration, spectral mean, or onset of frication energy of the prefixal sibilant when it is affixed to a stem containing an alveolar sibilant than when it is affixed to a stem containing no alveolar sibilants. For Female 1—at least for the parameters measured herein—an [ʃ] is an [ʃ].

That said, recall that differences in average spectral mean based on the continuancy specification of the stem sibilant approached significance for Female 1. This is particularly interesting when compared to Male 1's results, wherein pairwise comparisons found that the spectral means of adjacent stems and nonadjacent stems were significantly different from one another. Taken together, these findings—represented in (44)—support what has been suggested previously: when considering factors that contribute to gradience in Navajo sibilant harmony, continuancy and adjacency matter.

(44) Male 1 and Female 1: Adjacency and Continuancy

Male 1	SPECTRAL MEAN	adjacent > filler > nonadjacent
Female 1	SPECTRAL MEAN	noncontinuant > filler > continuant

Note that the measurement affected in both instances is spectral mean. This is very nice; recall that neither duration nor F2 transition proved useful in distinguishing between sibilants based on place of articulation. That being the case, if harmony affects the prefixal sibilant in some near-neutralized way then we need to look elsewhere to find evidence of it. That spectral mean is the parameter in which differences approached significance for both Female 1 and Male 1—albeit based on different independent variables—suggests that spectral characteristics are the right place to be looking for acoustic remnants of harmony.

If we consider the factors themselves, it is not surprising that adjacency matters—previous work on consonant harmony includes frequent mention of the important role played by distance in Navajo sibilant harmony (Martin 2005, Sapir and Hoijer 1967). Distance is also known to be more broadly phonologically important—i.e., it is relevant beyond the realm of consonant harmony, as witnessed by the OCP effects observed in, for example, Arabic (Frisch et al. 2004) and English and Latin (Berkley 2000). Male 1’s results as seen in (44)—wherein spectral mean is higher for adjacent stems than for nonadjacent stems—are thus consistent with the expected trend.

As for continuancy, the results in this thesis indicate an asymmetry in trigger strength based on manner of articulation, with noncontinuants seemingly acting as stronger triggers for assimilation. While not significant, the trend observed in Experiment I—the Google study—was for noncontinuant stems to show higher rates of assimilation, and in Experiment II assimilated forms of stems containing noncontinuants received higher grammaticality ratings than stems containing continuant. As seen in (44), Female 1 follows the pattern we would expect based on the previous studies, with the prefixal sibilant being numerically—though not significantly—more [s]-like, with a higher average spectral mean before noncontinuant stems than continuant stems. This came out in the grouped analysis, as well, with the prefixal sibilant showing a significantly higher spectral mean before noncontinuant stems than before continuant stems. Future experimentation should aim to shed light on the perceptual salience of noncontinuants—and of affricates, in particular. It should also investigate whether their apparent status as stronger triggers for assimilation Navajo is paralleled in other consonant harmony systems.

The other factor that proved relevant in grouped analysis was syllable position of the stem sibilant; the prefix had a higher spectral mean before stems containing sibilants in onset position than before those containing sibilants in coda position. Syllable position proved significant in Experiment II, as well, wherein speakers deemed the assimilated forms of stems containing onset sibilants as more grammatical than the assimilated forms of stems containing coda sibilants. As

mentioned in the discussion following Experiment II, there is evidence that syllable onsets are more salient than codas in the realms of speech perception (Treiman et al. 1995), in the strength of phonological constraints as evidenced in the statistical make-up of the lexicon (Berkley 2000), and in child acquisition of phonological awareness (Treiman et al. 1998). Though this should be investigated further, the results reported herein suggest that syllable position may be relevant in the phonological process of consonant harmony, as well.

It is worth noting that in the cases highlighted in (44), measurements of the prefix before filler stems falls in between the two target groups. This was briefly referenced in Section 4.4.4. At this point in time we can do nothing but point this out; it would be an interesting finding to investigate further in future studies, however.

Female 2's speech differed from the other participants in at least two ways. First, she is the only participant whose target vs. filler ANOVA indicated a clear difference between the prefixal sibilant before targets and fillers, and this difference was manifested in the mean onset of frication energy. No significant differences in the mean onset of frication energy were detected for the other speakers; further, the independent variable which yielded a clearly significant difference in the mean onset of frication energy was the voicing of the stem sibilant, which was not shown to play a role in producing significant differences elsewhere. The target vs. filler distinction did prove to trigger significant differences in mean onset of frication energy in the grouped analysis, however. This acoustic characteristic may provide

further ground for investigation in future work, as both Female 2 and the grouped analysis findings suggest that the presence of alveolar sibilants in the stem do trigger acoustic changes in the onset of frication energy of the prefixal [ʃ].

The same qualifiers that apply to the other studies included in this thesis apply here as well—more participants and larger sample sizes are highly desirable, and will hopefully allow for findings that attain—rather than merely approach—significance. Nonetheless, Female 2 and Male 1 pattern together in an important way; they evidence acoustic effects of a phonological pattern which they do not overtly practice. They do not pronounce the first person possessive morpheme as *si-* in a way that is audibly apparent. And yet in some way, for each of them, the onset sibilant in the prefix is acoustically different when preceding a noun that contains an alveolar sibilant than when preceding a noun that does not.

Is it possible that the diminished presence of consonant harmony in the speech of these three speakers can be attributed to a common cause, such as schooling or dialect area? Female 2 reported in conversation that although she learned the language in her home she also took informal Navajo language classes in high school, where they were overtly taught that the first person possessive morpheme was *shi-* and no mention of harmony was made. This could have ramifications for new learners, but Female 2 was already a speaker of Navajo—she acquired the language at home, as did Female 1 and Male 1.

It could also be the case that these speakers' sibilant harmony patterns are related to dialect, for it is well established that there are a variety of dialect areas on

the Navajo reservation (Peterson 1997, Reichard 1945). While I cannot make any strong assertions on this point with the amount of data currently on hand, I can say the following. While the three speakers recorded in this study are all from the northeast corner of the Navajo Nation in Arizona, as shown in (45), it seems unlikely that dialect area underlies their sibilant harmony patterns as they are from approximately the same area but show different acoustic patterns.

(45) Geographical Origins¹⁰



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Regardless of the fact that they are from the same relative dialect area, however, it should be pointed out that their idiolects clearly differ. In the first place, the words they produced when prompted were not entirely identical—one provided *yoostsah* as the word for ‘ring,’ for example, while another provided *latsa*. They also disagreed on the possessability of several words; for one speaker, neither ‘firewood’ nor ‘insect bite’ could be possessed; instead of ‘my insect bite,’ the speaker chose to

¹⁰ Generated on maps.google.com, accessed August 7, 2010

say something she translated for me as ‘the insect bites me,’ and the thought of saying ‘my firewood’ caused a gale of laughter. A second speaker reported that she would not say ‘my firewood,’ but that she had heard other people say it. The third speaker said ‘my firewood’ without pause.

What we are left with, then, is that we do not have enough information at this time to entertain any theories about where to trace the lack of overt assimilation of the first person possessive morpheme in their speech. There is some indication that assimilation is not being taught, but these speakers learned the language in their homes, and while they are from the same general geographical area, not enough is known about dialect areas in the Navajo Nation to make any claims related to dialect. In light of the Google study and internet survey findings, it seems more likely that sibilant harmony is diminishing; the previously mandatory environment is no longer mandatory, and optional harmony applies rarely—and for some speakers, never. An obvious question that has not yet been addressed is this: why is harmony disappearing? Is the phenomenon retreating back towards a co-articulatory effect rather than a phonological process? Potential catalysts for its disappearance—both language internal and language external—will be considered briefly in the next section.

5 Discussion, Challenges, and Future Directions

The studies presented in this thesis provide an interesting picture of gradient sibilant harmony in Navajo with regards to the first person possessive morpheme *shi-*. This process has been described as being mandatory when sibilants are adjacent and optional when there is more distance between them. The findings from Martin (2005) indicate that distance—and adjacency—should be assessed on the syllable level, but the present findings indicate that harmony is always optional, even when sibilants are in adjacent syllables. In addition, it appears that in the domain of nouns many current speakers never harmonize in optional environments—and if all environments are optional, then the result is that many speakers do not perform assimilation at all. A brief review of Experiments I, II, and III follows, in advance of a discussion about possible implications.

Experiment I used Google to investigate harmony patterns in online Navajo language use. The findings indicated that the first person possessive marker surfaced in its unharmonized form much of the time, even when affixed to nouns beginning with an alveolar sibilant. The overall assimilation rate was 36% in 2008 and 35% in 2010. The only factor shown to affect assimilation rates in Experiment I was adjacency; the prefix surfaced as the harmonized *si-* significantly more often when affixed to noun stems that contained alveolar sibilants in adjacent syllables than when affixed to those containing alveolar sibilants in nonadjacent syllables.

Experiment II elicited grammaticality judgments of the assimilated and unassimilated forms of nouns inflected for the first person possessive. The results

showed a preference for the unassimilated *shi-* in all instances; *si-* forms were dispreferred across the board. That said, some differences still emerged. The assimilated forms of nouns that contained noncontinuants (i.e. [ts, dz]) received higher ratings than those that contained continuants (i.e. [s, z]). The assimilated forms of nouns with alveolar sibilants in adjacent syllables were deemed better than the assimilated forms of nouns with nonadjacent alveolars, and the assimilated forms of nouns with alveolars in syllable onset position were deemed better than those with alveolars in coda position. In other words, even though assimilated forms were dispreferred overall, the factors of continuancy, adjacency, and syllable position significantly altered grammaticality ratings.

Experiment III investigated the speech of three speakers of Navajo to determine whether the prefixal sibilant was acoustically affected by the presence of alveolar sibilants in the noun stem. Impressionistically, none of them harmonizes; analysis revealed some interesting facts, however. When their data was grouped, the prefixal sibilant was shown to have a significantly higher onset of frication energy before targets than it did before fillers. It also proved to have a higher spectral mean before stems containing noncontinuant alveolar sibilants than before stems containing continuants, and before stems with alveolar sibilants in syllable onset position than before those with alveolar sibilant codas.

In sum, even if harmony is disappearing from these possessed nouns in Navajo, it is still affected by at least three factors. Adjacency was found to be a factor of significance in Experiments I and II, while continuancy and syllable

position were found to be of significance in Experiments II and III. We turn now to a discussion of these factors.

5.1 Gradience in a Disappearing Phenomenon

Upon investigation of gradience in Navajo sibilant harmony, distance comes to the forefront as a relevant factor. Stems that contain sibilants in syllables adjacent to the prefix are more likely to show assimilation in online language use, and are judged less harshly by speakers when assimilated. These findings are in keeping with previous studies which have highlighted the prominence of distance as an important factor in phonology—those mainly discussed in this thesis focused on OCP-Place violations in Arabic, English, Latin, and Muna, as well as laryngeal co-occurrence restrictions (Berkley 2000, Coetzee and Pater 2008, Frisch et al. 2004). If we turn from phonological processes at large and focus on an example specifically related to consonant harmony, we can consider the Bantu language of Kinyarwanda, wherein regressive harmony is mandatory for sibilants in adjacent syllables but optional for those in nonadjacent syllables (Walker and Mpiranya 2008). With regards to Navajo, the results obtained in this thesis also support the observation made by Sapir and Hoijer more than four decades ago about the salience of distance: “assimilation nearly always occurs when the two consonants are close together, but it occurs less often when the two consonants are at a greater distance” (Sapir and Hoijer 1967, p. 14-15). I would add that harmony is also better tolerated when

sibilants are nearer to one another, and is judged more harshly when there is more distance between them.

Taken together, Experiments I, II, and III also suggest that asymmetries in the salience of fricatives and affricates, or of continuants and noncontinuants, bear further investigation. Had similarity been key to determining the strength of a trigger-target relationship, we would have seen continuant alveolar sibilants acting as a stronger trigger for assimilation; yet this was not the case. In Experiments II and III, the results indicated that in fact noncontinuants are stronger triggers; noncontinuant stems were rated more grammatical than continuant stems when assimilated, and the prefixal fricative had a significantly higher—i.e., more [s]-like—spectral mean before noncontinuant stems than before continuant stems. Similarity is noted as being important in consonant harmony systems (Hansson 2001, Rose and Walker 2004); we must look beyond similarity to explain the findings in this instance, however, and research into the salience of the aforementioned consonant types seems to hold promise.

A finding that affricates are stronger triggers would be a relatively straightforward extension of knowledge we already possess; that is to say, we already know that there are trigger-target asymmetries with regards to place of articulation, for example. Some sounds—better said, some natural classes—are better triggers for phonological rules, and other sounds are more likely to be the targets of phonological rules. Future investigation into an affricate/fricative asymmetry in terms of trigger strength in other phonological domains might help to

shed light on the findings presented herein. It would also be advantageous to conduct an investigation of the specific triggers involved in sibilant harmony in other domains of Navajo, or in the sibilant harmony systems of other languages.

The results from Experiments II and III also indicate that alveolar sibilants in syllable onset position act as stronger triggers for harmony in Navajo; nouns containing alveolar sibilants in coda position were deemed less grammatical when affixed with the assimilated *si-* than nouns with alveolars in onset position. The prefix also showed a higher spectral mean when affixed to nouns containing alveolars in syllable onset than when affixed to those with alveolar codas. This, again, is not shocking; results from a range of phonological research has indicated the salience of syllable onsets (Berkley 2000, Sendlmeier 1987, Treiman et al. 1995).

One complicating factor in the present work arises from the use of relatively short noun lists; the factors discussed above are interconnected, and cannot be disentangled at the present time. More to the point, this research simply looked at onsets versus codas, at continuants versus noncontinuants; in the future, work may look at—for example—continuant onsets versus continuant codas, adjacent noncontinuant onsets versus nonadjacent noncontinuant onsets, and so forth. In addition, future investigation into the salience of noncontinuants and syllable onsets in trigger/target asymmetries in consonant harmony systems in other domains of Navajo and in other languages may yield results that will help shed light on the findings presented herein.

5.2 Additional Factors

Factors which have not been addressed in this thesis include, minimally, frequency effects, the statistical composition of the Navajo lexicon, and the Palatal Bias, all of which could impact the data. With regards to frequency information, the lack of a searchable Navajo corpus or dictionary makes it functionally impossible to obtain frequency data for Navajo words. It has been shown that neighborhood density contributes to gradient grammaticality judgments, however (Bailey and Hahn 2001, Coleman 1996, Ohala and Ohala 1986). Such data is therefore desirable, and should be sought in future studies. Lack of a searchable corpus or dictionary also makes it difficult to discuss the statistical make-up of the lexicon; we know from previous dictionary- and word list-based studies that such analyses can yield helpful results (Coetzee and Pater 2008, Frisch et al 2004, Zuraw 2002), and an online Navajo lexicon based on the Young and Morgan dictionary existed in (2005), but could not be accessed at the time of this research.¹¹ Thus an analysis of the number of nouns that contain palatal sibilants versus the number of nouns that contain alveolar sibilants, which could potentially help us to understand the bias against harmony found in this thesis, cannot be conducted at this time.

The concept of representation of alveolar and palatal sibilants in the Navajo lexicon is relevant in part because of the Palatal Bias. This term refers to the

¹¹ Whether it is accessible to a specific audience or will be more widely accessible again at some point in the future, I do not know.

asymmetry found in speech error corpora; in speech errors (in at least English and German), alveolars are replaced by palatals more often than palatals are replaced by alveolars (Stemberger 1991). This is clearly relevant to the current study because of the number of parallels between consonant harmony and speech errors noted by Gunnar Hansson in his 2001 doctoral dissertation about consonant harmony. The Palatal Bias is a term used to refer to asymmetries observed in the errors that are made in speech production (Stemberger 1991) and perception (Pouplier and Goldstein 2005). Briefly, alveolar segments like /s/ and /t/ are much more often mistakenly replaced with palatal segments like /ʃ/ and /tʃ/ in speech errors in English than vice versa; this despite the fact that the alveolar segments are higher-frequency and the palatal segments lower frequency in English (Hansson 2001, Stemberger 1991). Alveolars are regularly turned into palatals in speech errors; palatals are rarely turned into alveolars. Hansson reports that the same phenomenon has been found for German (Berg 1988) and in Hebrew (Bolozky 1978).

The Palatal Bias is worth considering for a moment because, as mentioned, Hansson reports startling similarities between consonant harmony and speech errors. To this end, he investigates sibilant harmony systems to determine whether there is evidence of a Palatal Bias in their typology. He finds that there is. There are symmetric and asymmetric harmony systems; thinking only about sibilant harmony, and using /s/ to represent all alveolar sibilants and /ʃ/ to represent all palatal sibilants, symmetric harmony systems are those in which underlying /s/ can

become /ʃ/ and underlying /ʃ/ can become /s/. The feature of anteriority spreads both ways, in other words; both segments can act as triggers, and both can act as targets. Ten of the sibilant harmony systems surveyed in Hansson (2001) are symmetric (p. 469).

In asymmetric harmony systems, harmony goes in only one direction; i.e., /s/ may be a target and /ʃ/ a trigger, but never the reverse. Alternately, /ʃ/ may be a target and /s/ a trigger, but not the reverse. The typology of asymmetric consonant harmony systems shows a clear imbalance in keeping with the Palatal Bias; while Hansson notes 16 languages that display asymmetric harmony that moves in the /s/ to /ʃ/ direction, he found only one—Tlachichilco Tepehua—that exhibits asymmetry in the /ʃ/ to /s/ direction (p. 472). These findings indicate that, typologically, /s/ is far more likely to serve as a target than as a trigger; conversely, /ʃ/ is a more likely trigger than target.

Navajo exhibits symmetric harmony; alveolar segments may act as both triggers and targets, and the same is true for palatals. However, in this research only the likelihood of /ʃ/ surfacing as [s] has been investigated; our understanding of the true nature of sibilant harmony as it exists in Navajo today cannot be complete without determining whether there are asymmetries in the behavior of underlying /s/ surfacing as [ʃ]. It may be the case that Palatal Bias effects will be found in Navajo sibilant harmony patterns; research centered on a morpheme that contains an underlyingly alveolar sibilant is needed to answer this question. Further, because Navajo is a verb-heavy language future work investigating the

assimilation of a verbal prefix that is underlyingly /s/ would allow us to complement the findings of this thesis.

5.3 Challenges in the Present Work: Diversity and Numbers

Several factors complicated analysis of the data presented herein, and should be addressed in future work. Balancing the wordlist so that groups had approximately the same number of words was a challenge in the first place—in particular, noun stems containing sibilants in adjacent syllables were more common than those containing sibilants in nonadjacent syllables. It was also a challenge to find stems with sibilants in coda position. The result was an imbalance between groups—for example, when thinking about the number of stem sibilants in Experiment I, 22 stems contained a single sibilant while 7 stems contained multiple sibilants. This imbalance could be remedied by the suggestion mentioned previously; a future study of optional sibilant harmony in Navajo wherein the morpheme of interest is a verbal prefix is an obvious next step.

This is a logical next step, regardless. Verbs are more common than nouns in Navajo; what would be a noun in English is often a verb in Navajo, as was typified by the story related above of the speaker who did not say “my insect bite,” but rather “The insect bit me.” While nouns share many important features with verbs in Navajo—for example, the onset of verb stems and noun stems are the only places where all consonant contrasts in the phonemic inventory of Navajo are found

(McDonough 2003, Oberly 2008)—they simply do not make up the bulk of Navajo. Thus future work will benefit from a focus on verbs.

It would also benefit both the power of the statistical tests and the generalizability of the results to increase numbers across the board—more speakers, more tokens, and more diversity in terms of demographic characteristics such as age and home towns. Although there was some diversity of ages represented in the grammaticality survey respondents, the three speakers recorded for the acoustic study were of nearly identical ages and were from very similar places geographically. Clearly we need to know more about the sibilant harmony patterns of older speakers and speakers from other parts of the Reservation.

That said, Navajo is an endangered language. The Ethnologue states that there are 149,000 speakers of Navajo, but this statistic is from the 1990 census and hardly reflects the real state of the language in 2010. It is generally accepted, however, that the language is in danger regardless of the current number of speakers because of the decline in child acquisition (Dick and McCarty 1999, Holm and Holm 1995, Webster 1996). As time goes by, fewer children are bilingual upon entering school: anecdotally, I have been told that only one in four children whose entire family speaks Navajo is acquiring Navajo as mother tongue. The threat of language loss is very real.

Of the many ramifications this loss will have, the way it affects researchers is nowhere near the top of the list. The functional results for researchers, however, are manifold. One factor which was not taken into account in the present study was

frequency—in any form, whether lexical or phonological. In fact, it would not have been possible to do so; there is no frequency data available for Navajo. It is also very difficult to collect a substantial amount of data. What we can say based on the findings presented herein, however, is that harmony seems to be disappearing.

This finding aligns with information gathered by the Navajo Rosetta Stone project. Based on a perception that most current learners of Navajo do not perform harmony, Rosetta Stone’s Navajo language consultants have engaged in a great deal of dialogue about whether the Navajo product should only use *shi-* when presenting the first person possessive morpheme. In their research on the matter, the Rosetta Stone project coordinators have determined that, with regards to the first person possessive morpheme, “Some people make the differentiation, but others don’t. This appears to be a matter of idiolect rather than dialect, dependent on the age and fluency of the speaker, as well as where they acquired the language from” (D. Hieber, personal communication, December 28, 2009).

This is yet more evidence that harmony is diminishing in Navajo. Let us now briefly consider some factors which may be contributing to its disappearance.

5.4 A Disappearing Phenomenon: Some Potential Causes

A consideration of diminishing patterns of sibilant harmony in Navajo must look at both language external and language internal factors. Further, a review of language external factors cannot neglect the influence of other languages, and of

English in particular. As stated previously, Navajo is an endangered language; child acquisition of Navajo is declining, while English language use is increasing (Schaengold 2004). In a 2004 doctoral dissertation, Schaengold reports that a nonstandard variety of Navajo (which she terms “Bilingual Navajo”) is spoken more and more commonly on the Navajo Nation, particularly by young people in urban areas around the edges of the Nation. Bilingual Navajo—heavily influenced by English, and including many English lexical items—does not hold high social prestige, but according to Schaengold it is increasingly present and is less socially marked as time passes. Schaengold notes that not all speakers apply sibilant harmony to lexical items in Bilingual Navajo; she also notes, however, that it is not uncommon to hear speakers produce ‘just’ as [dzʌs] or ‘Jesus’ as [dzi:zəs] (p. 90). The influence of English on Bilingual Navajo offers a clear example of how productions in one language can be modified by phonological rules from another language. English does not exhibit sibilant harmony; it is possible that this contributes to the minimal sibilant harmony found in this thesis.

As stated previously, I have also been told that students learning Navajo in school may be taught explicitly that the 1st person possessive morpheme is *shi-*, with no mention made of a possible alternation with *si-*. This information is anecdotal and replete with complications, so I will not discuss it in detail, but it should not be dismissed as a factor contributing to language change. Classroom learning provides very different exposure than children acquiring Navajo as a first language receive, in terms of amount and content. Classroom learning often involves a great deal of

instruction in reading and writing, which is absent from first language acquisition. The sibilant harmony visible in written Navajo has been useful in this work because investigation of harmonization patterns could be conducted on written language in online domains. However, the ways in which orthography may influence spoken Navajo remain to be studied. Further, neither the way the first person possessive morpheme is presented in Navajo language classes nor issues related to orthography are relevant to the findings of the acoustic study presented in this thesis, as the three participants recorded therein acquired Navajo in their homes as children.

Although her work on the sound system of Navajo deals almost exclusively with verbs, rather than consonant harmony, McDonough (2003) does touch on a number of points of interest related to harmony. She observes that because sibilant harmony neutralizes a place of articulation contrast, it further limits an already limited set of place of articulation contrasts (p. 49). McDonough goes on to ask, “why would a language with an already reduced set of place of articulation contrasts further reduce its phonemic inventory by disallowing contrasts among the coronal consonants?” (p. 49). This is interesting to consider, yet the neutralizations triggered by sibilant harmony are not unique in Navajo, a language in which the full inventory of sounds can be realized in very few locations within words (namely verb and noun stems) and wherein neutralization occurs in many contexts.

McDonough’s next point deals with the actual physical instantiation of sibilant harmony, and as such it is directly relevant to the current work particularly

with regards to the acoustic study in Experiment III. Namely, is consonant harmony in Navajo a categorical process in which one segment is replaced outright by another, or is it possible that it is instead a more phonetically gradient effect? The current findings do not point to any answers because none of the speakers recorded herein proved to be active harmonizers. Thus the question remains open, at least until it is possible to conduct acoustic analysis of the productions of an active harmonizer.

Language internally, another possibility that can be considered deals with exposure. Perhaps learners are exposed to very few examples of the kind of sibilant harmony that has been discussed herein; if this is the case, learners may simply resist making generalizations. This is not a wild supposition; verbs are much more numerous in Navajo than nouns (McDonough 2003, p. 2). This is a complex issue, but if we entertain this as a possibility, we can consider whether the findings from the acoustic study support an analysis of recession towards co-articulation. Perhaps significantly more s-like measurements in the prefixal sibilant triggered by the presence of an alveolar sibilant in the noun stem are not remnants of harmony, but are rather indications of a co-articulatory effect which preceded the harmony process. This leads back to McDonough's question about whether sibilant harmony in Navajo involves categorical replacement or phonetically gradient productions, a question which invites future investigation.

6 Conclusion

Sibilant harmony in Navajo holds interest for a number of reasons. On a purely superficial level, consonant harmony as a phonological phenomenon is relatively rare and is therefore exciting. Consonant harmony exhibits optionality, and provides an excellent arena in which to investigate gradience. That said, relatively little work has been done on Navajo sibilant harmony. While further investigation is needed, the findings presented herein challenge previous beliefs about the existence of a mandatory harmony environment, and show a great deal more optionality than anticipated. The present data indicate the importance of the distance between trigger and target sibilants and the manner of articulation of trigger sibilants, suggesting a possible affricate-fricative asymmetry in terms of strength of trigger. Finally, the present data show that stem sibilants may have dissimilatory acoustic effects on prefixal sibilants even for speakers who show no evidence of harmony that can be perceived by the human ear. It is possible that more questions have been raised than answered, but it is my hope that future studies will benefit from the groundwork it has laid.

Appendix A: QueryGoogle Noun List and Assimilation Rates

NAVAJO WORD		PROPORTIONS (SI-FORMS/TOTAL NUMBER OF TOKENS FOR STEM)		ASSIMILATION RATE		ASSIMILATION RATES ADJUSTED FOR RELIABILITY ¹²	
		S08	S10	S08	S10	S08	S10
1.	'atsa <i>abdomen</i>	2/2	-	1	-	0.50	-
2.	'azee <i>mouth</i>	0/2	0/1	0	0	0.04	0.07
3.	béeso <i>money</i>	0/16	0/70	1	0	0.01	0.00
4.	bis <i>adobe/clay</i>	0/7	20/52	0	.39	0.02	0.31
5.	-dziil <i>strength</i>	4/6	12/20	.67	.6	0.43	0.47
6.	k'is <i>friend</i>	232/309	488/886	.75	.55	0.72	0.53
7.	k'os <i>neck</i>	0/1	1/2	0	.5	0.07	0.22
8.	kaz <i>cane</i>	0/3	3/4	0	.75	0.03	0.44
9.	látsíní <i>bracelet</i>	0/3	0/1	0	0	0.03	0.07
10.	mósi <i>cat</i>	0/5	1/9	0	.11	0.02	0.06
11.	naaltsoos <i>book</i>	0/7	0/9	0	0	0.02	0.01
12.	-tsa <i>body</i>	1/1	4/6	1	.67	0.35	0.43
13.	tsásk'eh <i>bed</i>	3/3	1/1	1	1	0.60	0.35
14.	tsii' <i>hair</i>	5/8	9/20	.63	.45	0.42	0.33
15.	tsiits'iin <i>engine</i>	8/8	12/16	1	.75	0.79	0.60
16.	tsili <i>younger brother</i>	36/45	131/168	.8	.78	0.72	0.74
17.	-tsis <i>frame of body</i>	2/2	5/5	1	1	0.50	0.71
18.	tsoi <i>cross cousin</i>	22/25	78/87	.88	.90	0.77	0.85

¹² Adjusted Reliability: Lower Confidence Limit ($\alpha = 0.75$); calculated exact confidence intervals for proportions, http://www.causascientia.org/math_stat/ProportionCI.html

19.	tsoo <i>tongue</i>	0/2	2/5	0	.29	0.04	0.22
20.	wos <i>shoulder</i>	5/6	2/5	.83	.4	0.57	0.22
21.	yaats'iin <i>chin</i>	-	0/1				0.07
22.	-zaad <i>language</i>	1/9	1/104	.11	.01	0.06	0.01
23.	za'azis <i>pocket</i>	1/1	2/2	1	1	0.35	0.50
24.	zagi <i>esophagus</i>	2/2	3/3	1	1	0.50	0.60
25.	zazi <i>ancestor</i>	1/1	1/2	1	.5	0.35	0.22
26.	-zee <i>mouth</i>	17/18	9/15	.94	.6	0.82	0.45
27.	zeedi <i>nephew</i>	3/10	3/16	.3	.19	0.18	0.12
28.	zid <i>scar</i>	1/4	7/14	.25	.5	0.13	0.36
29.	ziiz <i>belt</i>	96/98	142/145	.98	.98	0.95	0.96

Appendix B: Qualtrics Survey Noun List¹³

FILLERS	
1. ach'oozhlaa'	<i>elbow</i>
2. ajaa'	<i>ear</i>
3. awoo'	<i>tooth</i>
4. bid	<i>stomach</i>
5. ch'ah	<i>hat</i>
6. ch'osh hashhash*	<i>insect bite</i>
7. ch'ozh	<i>calf</i>
8. chaii	<i>maternal grandfather</i>
9. chizh*	<i>firewood</i>
10. daa'	<i>lip</i>
11. doh	<i>muscle</i>
12. gaan	<i>arm</i>
13. gish	<i>walking stick</i>
14. god	<i>knee</i>
15. honishgish	<i>fire poker</i>
16. hooghan	<i>home</i>
17. jeeh	<i>chewing gum</i>
18. jizhgish*	<i>cut</i>
19. k'a'	<i>arrow</i>
20. kee'	<i>foot</i>
21. naanish	<i>work</i>
22. nii'	<i>face</i>
23. yid	<i>chest</i>
24. yih	<i>breath</i>
25. zhi'	<i>torso</i>
TARGETS	
26. agaanstsiin	<i>guitar</i>
27. ak'inaazt'i'	<i>harness</i>
28. atsoosk'id	<i>thigh</i>
29. ayaats'iin	<i>chin</i>
30. bii'dees'eez	<i>stirrup</i>

¹³ For general commentary on nouns, see the notes at the end of this Appendix. Nouns requiring specific commentary are annotated with asterisks.

31. bis	<i>clay</i>
32. bits'a'	<i>peapod</i>
33. bizis	<i>pack (of gum, cigarettes, etc)</i>
34. dahts'aa'	<i>mistletoe</i>
35. das	<i>weight</i>
36. dikos	<i>cough</i>
37. dikos'azee'	<i>cough syrup</i>
38. doolghas	<i>scallop</i>
39. dziil	<i>strength</i>
40. (ha)st'e'	<i>(his) lunch</i>
41. hatsi'	<i>daughter</i>
42. haza'aleetsoh	<i>wild celery</i>
43. haza'aleeh	<i>herbs</i>
44. heeneez*	<i>rectangle</i>
45. hootso	<i>pasture</i>
46. k'iiz	<i>side</i>
47. k'is	<i>sibling, friend</i>
48. k'os	<i>neck</i>
49. kaz	<i>cane</i>
50. naaltsoos	<i>book</i>
51. naaltsoos azis	<i>shopping bag</i>
52. sin	<i>song</i>
53. sodizin	<i>prayer</i>
54. t'iis	<i>Cottonwood tree</i>
55. ta'azis	<i>pocket</i>
56. tin sikaad*	<i>rink (for ice skating, etc)</i>
57. ts'aa	<i>basket</i>
58. ts'iizis	<i>head basket</i>
59. ts'in	<i>bones</i>
60. ts'oos	<i>nerve</i>
61. tsah	<i>needle</i>
62. tsee'	<i>tailbone</i>
63. tsii'	<i>hair</i>
64. tsiits'in	<i>skull</i>
65. tsiizis	<i>scalp</i>
66. tsits'aa	<i>wooden box</i>
67. tsoi	<i>cross cousin</i>

68. tsoo'	<i>tongue</i>
69. wos	<i>shoulder</i>
70. yisdis	<i>roll (of toilet paper)</i>
71. yoostsah	<i>ring</i>
72. za'azis	<i>pocket</i>
73. zid	<i>liver</i>
74. ziiz	<i>belt</i>
75. zis	<i>bag</i>

*There was some debate amongst my consultants with regards to which nouns could be possessed and which could not. At least one consultant considered each of the following words unpossessable, ungrammatical, or both.

- ch'osh hashhash, *insect bite*
- chizh, *firewood*
- jizhgish, *cut*
- heeneez, *rectangle*
- tin sikaad, *(skating) rink*

I did not exclude these words from the list, however, because one or more of my consultants had a differing opinion and considered it grammatical to create the possessed form of them. In some cases this meant they had used a possessed form themselves; in others, they had simply heard or seen a possessed form used by someone else.

Appendix C: Acoustic Study Personal Information Questionnaire

The following questionnaire is intended to collect personal information. Neither your name nor any other personal information will be associated in any way with the data collected in this experiment, or with the research findings from this study. The researcher will use a participant number, initials, or a pseudonym instead of your name.

1. I speak Navajo with my parents.
a lot a little not at all This question doesn't apply to me.
2. I speak Navajo with my grandparents.
a lot a little not at all This question doesn't apply to me.
3. I speak Navajo with my siblings and/or friends.
a lot a little not at all This question doesn't apply to me.
4. We spoke Navajo in my home when I was growing up.
a lot a little not at all This question doesn't apply to me.
5. I can read and write in Navajo.
a lot a little not at all This question doesn't apply to me.
6. Reading and writing in Navajo is
easy kind of easy okay kind of hard hard
7. I am _____ years old.
8. I am male. I am female. (please circle one)
9. What town/city (or towns/cities) did you grow up in?

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