THE PERCEPTION OF GERMAN DORSAL FRICATIVES BY NATIVE SPEAKERS OF ENGLISH

by

RENEE LORRAINE KEMP

(Under the Direction of Keith Langston)

ABSTRACT

German contains two dorsal fricatives, [ç] and [x], which occur in complementary distribution following vowels as part of a process known as dorsal fricative assimilation. This study proposes using speech perception to analyze dorsal fricative assimilation, and determine which dorsal fricative is underlying. A fixed AX listening experiment was conducted with 42 native English speakers as participants using stimuli produced by a native German speaker. Using a statistical analysis, which included participant responses and response times, [ç] was found to be the least perceptually distinct of the four fricatives tested. Additionally, the pair [ç] – [x] was found to be the least perceptually distinct of all six pairs tested. The data indicate that perceptual pressures eliminate an unproductive contrast through dorsal fricative assimilation, and from a perceptual standpoint, [ç] is a weaker candidate than [x] for the underlying dorsal fricative.

INDEX WORDS: fricatives, speech perception, phonology, assimilation, German

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DEDICATION

My thesis is dedicated to my parents, Robert and Laura Kemp, and my grandmothers, Jeri Kemp and Mary Adler, for their unending encouragement and support.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

CHAPTER 1

INTRODUCTION

The following work examines the perception of voiceless dorsal fricatives in German by native speakers of English, and whether a connection exists between the relative perceptual distinctiveness of dorsal fricatives and the phonological process of dorsal fricative assimilation. Dorsal fricative assimilation is a phonological process in German wherein the distribution of the voiceless palatal fricative [ç] and the voiceless velar fricative [x] is restricted based on the backness of the preceding vowel. As is discussed in more detail in section 1.2, there has been a substantial amount of debate regarding the direction in which this assimilation occurs, and subsequently, which dorsal fricative is the underlying form.

The perceptual experiment conducted with a fixed (non-roving) AX discrimination task. A native German speaker produced all stimuli for the listening experiment, including ungrammatical stimuli. Forty-two native English speakers participated as subjects for the listening experiment. Native English speakers were selected as participants for the listening experiment in an attempt to capture language-independent results, since English lacks both [ç] and [x], and the unfamiliarity of native English speakers with these sounds can provide a more universal assessment of the perceptual distinctiveness of dorsal fricatives (see Kaplan 2009 and Mann 1986 for additional studies testing language-independent and universal perception). A greater understanding of the language-independent perception of [ç] and [x], both individually and as a pair, can possibly inform us of the interaction between phonetics and phonology in the system of German dorsal fricative assimilation. Also of interest is whether or not the most phonetically contrastive system manifests in the phonology of German, or if the phonological system simplifies the most phonetically contrastive system (see Gordon 2002).

Through my examination of the subjects' identification of stimuli, along with response times, I conclude that [ç] is the least perceptually distinctive of the four voiceless fricatives that participants were asked to discriminate, [s], [ʃ], [ç], [x]. I also argue that the fricative pair [ç] - [x] has the least perceptual contrast of all possible pairs, which has implications for the process motivating German dorsal fricative assimilation and the vowels conditioning the environment in which this assimilation occurs. Because [ç] and [x] have a higher degree of confusability, and [ç] is least perceptually distinct of the four fricatives tested, German dorsal fricative assimilation can be explained from a perceptual standpoint as the least productive phonetic contrast of the four fricatives tested. Speech perception provides less evidence indicating which dorsal fricative is underlying in German, although the d-prime analysis discussed in Chapter 5 indicates that [ç] is identified as "different" in same pairs more than any other fricative. The perceptual confusion surrounding [ç] could indicate that it is less likely than [x] to be the underlying dorsal fricative in German; however, phonological approaches stating that [ç] is underlying (see Borowsky 1993, Merchant 1996, & Jensen 2000) provide convincing evidence based on the more restricted distribution of [x] compared to [ç].

In the conclusion, I argue for further analysis of the acoustic characteristics of dorsal fricatives. While work on the acoustic characteristics of English fricatives (see Jongman, Wayland & Wong 2000) and labial and coronal fricatives cross-linguistically (see Gordon, Barthmaier & Sands 2003) has furthered the general understanding of the distinguishing characteristics of fricatives, dorsal fricatives have remained largely unstudied. The brief acoustic analysis conducted within this study compared the Center of Gravity measurements of fricatives against each other in order to distinguish a criterion for each type. I argue that investigation of the interaction between formant transitions and dorsal fricatives needs further analysis. Stevens (1989) reports that the lowest resonance peak of [ç] corresponds to the third formant of the preceding vowel, and the lowest resonance peak of [x] corresponds to the second formant of the preceding vowel, which means that rounded back vowels preceding [ç] could potentially cause its auditory signal to resemble that of [x] even though the Center of Gravity of [ç] is still higher than that of [x].

Figures 1 and 2 below, which present spectrograms of [çi] and [xu], respectively, support Stevens' claim. Both spectrograms were generated with Praat (Boersma & Weenink 2011) using sound recordings from a native German speaker. All spectrograms show the frequency range between 0 and 8,000 Hz.

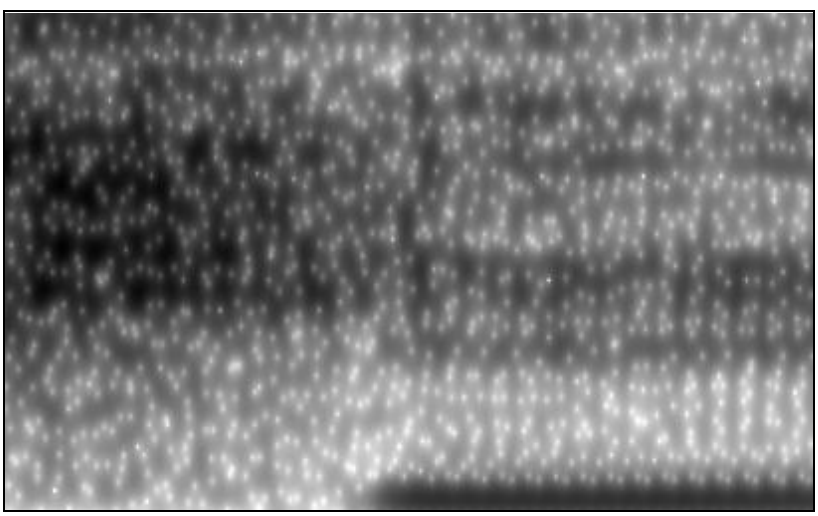
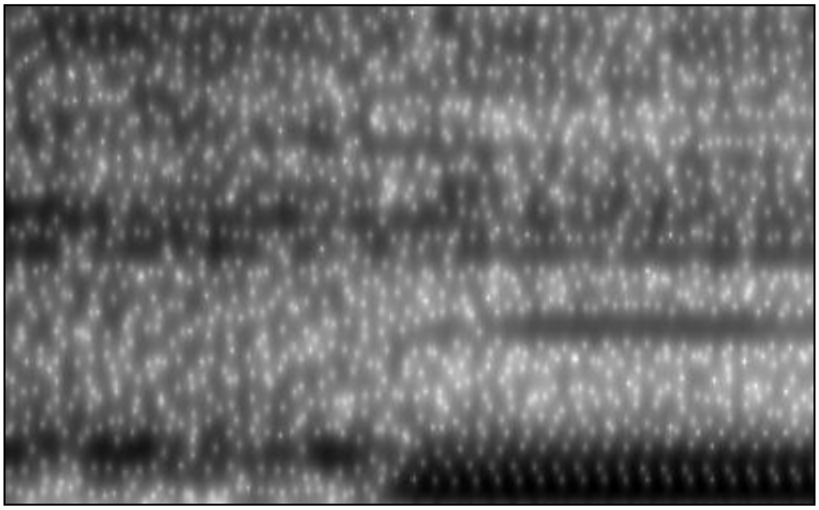


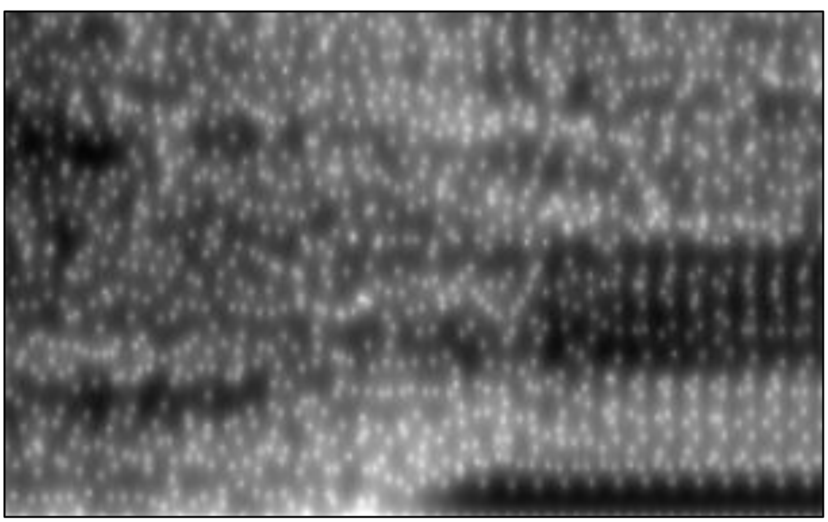
Figure 1. Spectrogram of [çi]



x u

Figure 2. Spectrogram of [xu]

The spectrograms of [ç] and [x] in grammatical pairings clearly show that the largest concentration of energy for [ç] corresponds to the F3 of [i] and the largest concentration of energy for [x] corresponds to the F2 of [u].



x i

Figure 3. Spectrogram of [xi]

Figure 3 indicates that Stevens' claim holds true even with the ungrammatical pairing of [x] with the front vowel [i], where the largest concentration of energy in the fricative [x] curves upward match the F2 of [i].

1.1 GERMAN DORSAL FRICATIVE ASSIMILATION

Voiceless fricatives in Standard German are present in the three major places of articulation, labial, coronal, and dorsal, with the majority of these fricatives concentrated in the coronal and dorsal regions (German only has one voiceless labial fricative, [f]). The coronal fricatives of Standard German, [s] and [ʃ], are phonemic and form minimal pairs such as *Maße* 'measures' [ma:sə] and *Masche* 'mesh' [ma:ʃə]. While there is no controversy regarding whether or not [s] or [ʃ] are phonemic in German, they provide a counter example to the question of which dorsal fricative, [ç][1] or [x], is underlying because there is no clear minimal pair distinguishing the latter two, nor would we expect to find one due to dorsal fricative assimilation. Clearly, the two German coronal fricatives are contrastive when paired against each other, yet the dorsal fricatives are not. Is there a unique feature or characteristic of the dorsal fricatives which motivates dorsal fricative assimilation, and prevents [ç] and [x] from occurring within the same environment?

In order to begin an overview of the various arguments and approaches in which dorsal fricative is underlying, and how the process of dorsal fricative assimilation occurs, I will begin by providing minimal pairs as data to illustrate the complexity of dorsal fricative assimilation. Both [ç] and [x], respectively, can create minimal pairs that form a three-way contrast with [s] and [ʃ]. The set *wissen* 'to know' [vɪsɛn], *wischen* 'to wipe' [vɪʃɛn], and *wichen* 'to leave 3.PL.PST' [vɪçɛn] is an example of a three-way contrast between [ç], [s], and [ʃ], and *Laus* 'louse' [laʊs],

[1] For the purposes of this paper, [ç] is treated as a solely dorsal consonant following Hall (1997).

lausch ‘to listen IMP.’ [laʊʃ], and *Lauch* ‘leek’ [laʊx][2] demonstrates a three-way contrast between [x], [s], and [ʃ]. Additional minimal pairs with two-way contrasts can be formed between [ç] - [s], [ç] - [ʃ], [x] - [s], and [x] - [ʃ]; however, as the data demonstrate, while [s] and [ʃ] are not restricted in whether or not they occur following a front vowel or a back vowel, [ç] normally occurs following a front vowel, and [x] after a back vowel, as shown in the examples above. The distribution of [ç], however, is subject to more complexities than vowel backness, as seen in Figure 4 below.

a. Examples with [ç]:	b. Examples with [x]:
Gespräch ‘talk’ [gɛʃpʁe:ç]	*Sprache* ‘speech‘ [ʃpʁa:xə]
Bücher ‘book PL.’ [by:çɐ]	*Buch* ‘book’ [bu:x]
echt ‘real’ [ɛçt]	*Macht* ‘power’ [ma:xt]
Kuhchen 'cow DIM.’ [ku:çən]	*Kuchen* ‘cake’ [ku:xən]
solch ‘such’ [zɔlç]	
Charisma 'charisma' [çaʁɪsma]	

Figure 4. Examples of the distribution of [ç] and [x]

The most apparent difference between columns a. and b. is the distribution of vowels by backness with exclusively [+back] vowels in column b. Figure 4 also illustrates that a thorough explanation of dorsal fricative assimilation is not as simple as stating that [ç] occurs after front vowels and [x] occurs after back vowels. The complexities revealed by Figure 4 are the fact that while both [ç] and [x] can precede the obstruent consonant [t], only [ç] can follow a sonorant consonant, such as [l], as seen in Figure 4. Figure 4 also shows that only [ç] can occur word initially; however, some have raised objections to this (see Hall 1992 and Russ 1982). In

[2] I would like to thank Dr. Vera Lee-Schoenfeld for providing me with these examples.

particular, Hall (1992) states that [x] can occur word initially in foreign loanwords such as *Junta* ‘junta’ [xu:nta], and Russ (1982) argues that [x] can occur syllable initially in words such as *Achat* ‘agate’ [a:xat]. While these arguments provide intriguing counterexamples, they seem to be exceptional cases, and although word initial [ç] is found primarily in loan words (Russ 1982), these loan words are far more common and lexicalized in German than loan words pronounced with initial [x].

Figure 4 also contains the pair *Kuhchen* and *Kuchen* which is an intriguing example for several reasons. First of all, this pair is seemingly distinguished only by the contrast of [ç] and [x], and initially appears to be a minimal pair; however, Hall (1992), Borowsky (1993), Merchant (1996), and Rauch (2008) all argue against *Kuhchen* as evidence that [ç] and [x] can contrast in German because dorsal fricative assimilation occurs before the affixation of the diminutive morpheme “-chen” [-çən]. In mono-morphemic words, [ç] and [x] never occur within the same phonetic environment, and thus, can never form minimal pairs. Secondly, although *Kuhchen* initially appears to be an example of [ç] following a back vowel, the morpheme boundary between *Kuh* and “-chen” means that words such as *Kuhchen* provide additional support for the claim that [ç] occurs word initially[3].

Figure 5, below, uses distinctive features to list the environments in which [ç] and [x] occur in mono-morphemic words. [ç] can surface word initially and following both front vowels and sonorant consonants. That [ç] can occur following a sonorant consonant has been used by both Gussmann (2002) and Merchant (1996) as supporting evidence for [ç] as the underlying dorsal fricative. In addition, syllabification factors heavily into Merchant’s account of dorsal

[3] Dr. Vera Lee-Schoenfeld also notes that [ç] with the back vowel [u] sounds unnatural to her, and in natural speech, a German speaker might be more likely to pronounce *Kuhchen* with a rounded front vowel such as [y].

fricative assimilation (see Chapter 2). [x], by comparison, can only occur immediately after back vowels.

[ç]: # __, [-back, +son.] __ #[4]

[x]: [+syll., +back +son. –cons.] __ #

Figure 5. Distribution of [ç] and [x] in mono-morphemic words.

While [ç] has a less restricted distribution than [x] in the mono-morphemic words of Standard German, and the majority of recent approaches favor [ç] as the underlying dorsal fricative (see Merchant 1996), [x] has traditionally been described as phonemic (see Trubetzkoy 1969 and Russ 1978), because [x] is less marked cross-linguistically, and [x] is believed to be the historical dorsal fricative in Germanic. In the next section, I will provide a brief overview of some approaches that scholars have used to investigate the question of German dorsal fricative assimilation.

1.2 PREVIOUS RESEARCH ON GERMAN DORSAL FRICATIVE ASSIMILATION

In the traditional explanation of dorsal fricative assimilation discussed in the previous section, [x] is the underlying dorsal fricative, and as such moves forward to surface as [ç] when preceded by a front vowel, as seen in Figure 6 below.

[-son, +cont, DORS] → [-back] / [-cons, -back] __

Figure 6. Dorsal fricative assimilation with underlying [x]

More recent accounts of dorsal fricative assimilation, such as Hall (1992), use a rule in which neither [ç] nor [x] are underlying. Instead, the underlying dorsal fricative, which is not specified for place, matches the backness of the preceding vowel, as seen in Figure 7.

[4] Additionally, the [+back] consonant, [ʁ] can precede [ç], as in *Storch* 'stork' [ʃtɔʁç].

[–son, +cont, DORS] → [αback] / [–cons, αback] ___

Figure 7. Dorsal fricative assimilation with no unique underlying fricative

The explanation of dorsal fricative assimilation described in Figures 6 and 7 above has been unsatisfying for many researchers because of examples cited in Figure 4, where [ç] can occur word initially. In Merchant's (1996) Optimality Theory (OT) account of dorsal fricative assimilation, he argues that [ç] is underlying and [x] only surfaces when it occurs in a coda and becomes syllabified. Gussmann (2002) also argues that [ç] is underlying and [x] only occurs to minimize articulatory effort.

Hall (1992) presents a more moderate approach to the question of which dorsal fricative is underlying with his rule of Dorsal Fricative Assimilation (DFA), which "spreads the feature [back] from a vowel onto an immediately following dorsal fricative," (222) which he represents as /X/, or an unspecified dorsal. In his discussion of German dorsal fricatives, Hall argues that since dorsal fricatives are unspecified in German, [ç] surfaces word initially more often, but [x] can occur word initially as well in words such as the previously discussed example, *Junta.* Interestingly, Hall expresses some doubts regarding the use of either dorsal fricative word initially in colloquial German. In particular, Hall claims that some German speakers replace the word initial [x] in foreign loanwords such as *Junta* with [h], and, additionally, most speakers would replace word initial [ç] in words such as *Cholesterin* 'Cholesterol' [çolɛsteʁi:n] and *Charisma* 'charisma' [çaʁɪsma] with [k]. The last two examples, however, are particularly obscure, and more speakers would be likely to use [ç] in words such as *Chemie* 'chemistry' [çɛmi:] or *China* 'China' [çina:], which, interestingly enough, both have front vowels immediately following [ç]. Whether or not there is a correlation between the surface representation of word initial [ç] and front vowels needs further investigation.

Finally, Kohler (1990) argues that there are three voiceless dorsal fricatives in German, [ç], [x], and [χ], which also undergo place assimilation; however, he does not claim any one fricative is underlying. Kohler states that [χ] occurs following low back vowels, and occasionally, the low mid back vowel [ʊ] and the diphthong [aʊ], whereas [x] appears after high and mid tense vowels. Since [x] and [χ], according to Kohler's description, are both restricted to non-word initial positions following back vowels, the distinction between [x] and [χ] does not need to be addressed; however, Kohler's claim merits further investigation, especially in regards to the acoustic characteristics of dorsal fricatives in German, and using Center of Gravity measurements (which is discussed in more detail in Chapter 3) to differentiate fricatives.

CHAPTER 2

PREVIOUS STUDIES: PERCEPTION AND PHONOLOGY

The previous approaches to the question of German dorsal fricative assimilation address the direction of assimilation and which fricative (if any) is underlying through the articulatory processes or distinctive features of the palatal and velar fricatives and the environments in which they occur. Far fewer studies have used perception to examine dorsal fricative assimilation. Weber (2001) reports the results of four experiments conducted by the author on the perception of assimilation violations, of which the first experiment studies the processing of violations of dorsal fricative assimilation by native German speakers. In this experiment, native German speakers listened to stimuli comprised of nonce words produced by a native Dutch speaker who also speaks German. Dutch does not have dorsal fricative assimilation, and the stimuli were judged Dutch-like by another native speaker of Dutch. The stimuli contained [x] in the penultimate position following both front and back vowels, and participants were asked to respond when they heard [x], which was presented to the subjects in German orthography as "ch.[5]"

In previous studies on the processing of types of assimilation that do not occur in participants' native languages cited by Weber (2001), participants exhibited an inhibition effect as demonstrated by longer response times (RTs). Weber (2001) found that ungrammatical pairings of [x] with front vowels actually had a facilitation effect for the speech processing of the German speakers, and when subjects were presented with stimuli that violated dorsal fricative

5 [ç] was not tested.

assimilation RTs were faster than when grammatical items were presented. The facilitation of ungrammatical pairs seems to indicate that there is an interaction between phonological rules and speech processing.

Weber then presents the same stimuli to native Dutch speakers in the second experiment reported in the same article. For the native Dutch speakers the differences in RTs between [x] preceded by a back vowel and [x] preceded by a front vowel were not statistically significant. Weber's findings seem to suggest that the phonological rule of dorsal fricative assimilation has some effect on the processing of [x] in ungrammatical pairings that does not occur with subjects from languages which lack dorsal fricative assimilation.

Steinberg, Truckenbrodt, and Jacobsen (2010) conducted a study on the pre-attentive speech processing of [ç] and [ʃ] by native German speakers using stimuli in which all pairings of [ʃ] were grammatical and both grammatical and ungrammatical pairings of [ç] were used. All stimuli were produced by a native German speaker. The study found that the ungrammatical instances of [ç] that violated dorsal fricative assimilation elicited a negative-going deflection in the event-related potentials (ERPs) of participants, which means that they processed [ç] with back vowels as unexpected mismatches. The authors argue that the pre-attentive processing of mismatched pairs indicates that phonotactic knowledge, such as dorsal fricative assimilation, is stored in the long-term memory of speakers.

Together, these two studies show that speakers of Standard German, who have dorsal fricative assimilation as part of their mental grammar, are acutely aware of violations of dorsal fricative assimilation, and in Weber (2001) the author concludes that the violations of German dorsal fricative assimilation that occur in the Dutch-like words used as stimuli facilitate the processing and recognition of [x] by participants. Similarly, the findings of Steinberg, Truckenbrodt, and Jacobsen (2010) show the effect of violations of dorsal fricative assimilation with [ç], rather than [x], at the pre-attentive speech processing level. Neither study, however, discusses the acoustic characteristics of [ç] and [x], the perceptual salience of either sound, or whether dorsal fricative assimilation eliminates an unproductive contrast between sounds.

Flemming (2002) argues in his Dispersion Theory of Contrast that languages maximize contrast within their phonological system. In particular, Flemming argues that there are three main criteria that motivate the preference for one phonological contrast over another:

- Maximize the number of contrasts.
- Maximize the distinctiveness of contrasts.
- Minimize articulatory effort. (Flemming 2002: 15).

Flemming's claim that languages tend to utilize the most distinctive contrasts within their sound inventory is especially relevant to my examination of dorsal fricative assimilation, because [ç] and [x] do not contrast with each other in German. Could the lack of a contrast between these two sounds be motivated by perception? Steriade's (2001) assertion that assimilation is a type of contrast neutralization seems to support initial assumptions that dorsal fricative assimilation is connected to the relative perceptual distinctiveness of [ç] and [x].

Padgett and Zygis (2007) use Dispersion Theory to examine the non-assimilatory retroflexion of sibilants in Polish and Russian, arguing that perception must be incorporated into any account of this sound change because, with a model entirely focused on articulatory effects, the process could not be explained. Padgett and Zygis (2010) expand on the conclusions drawn in Padgett and Zygis (2007) by conducting a perceptual experiment based on an AX listening task of the Polish sibilants [s], [ɕ], [ʃʲ], [ʂ], with two groups of participants, native Polish speakers and native English speakers. Like Padgett and Zygis (2007), the authors seek to motivate sound change in Polish, and other Slavic languages to a lesser extent, using evidence from speech perception, and they conclude that both Polish and English speakers had difficulty discriminating the same fricative pair, [ɕ] - [ʃʲ], which indicates that a perceptual difficulty motivated sound change in Polish.

In Kingston (2007), several production studies are reported to support his argument that speakers have an auditory, rather than articulatory goal. One such study, Riordan (1977), details an experiment in which participants were prevented from rounding their lips as they are asked to produce rounded vowels. To compensate for this articulatory restriction, participants lowered their larynges more than normal in order to create a longer vocal tract corresponding to a hyper-articulated version of the process that occurs during the production of rounded vowels (Lindblom & Sundberg 1971).

Dorsal fricative assimilation has been attributed to an articulatory effect (see Gussmann 2002); however, the studies reported by Kingston indicate that speakers will perform complex articulatory processes in order to increase the ease of auditory perception for listeners. Although it is possible that German dorsal fricative assimilation occurs due to some kind of articulatory effect, the perception of dorsal fricative assimilation merits further research. Of particular note is whether or not dorsal fricative assimilation neutralizes the otherwise minimally contrastive fricative pair [ç] – [x]. All of the previously mentioned studies influenced the experiment design detailed in chapters 3 and 4, because they present alternative approaches to understanding phonological processes.

CHAPTER 3

MATERIALS

Three participants were recruited to produce stimuli for the listening experiment. Participants were recruited through the distribution of an informational letter to the Department of Germanic & Slavic Studies at the University of Georgia. All participants were required to be eighteen years old or older, native speakers of German, and have no known hearing problems. All participants in the speaking portion of the experiment were eligible for the study based on their responses to a screening questionnaire (see Appendix B for the screening questionnaire, elicitation script, and other materials) which was administered before recording. The same elicitation script was used for each speaker. Each token was read within the same carrier sentence, Ich hab' X gesagt 'I have said X.' The carrier sentences with the tokens inserted were presented to participants in blocks of four sentences. Each of the four tokens within a block differed in fricative type and matched in both syllable order (CV or VC), and vowel ([i], [u], [o], [e]). The elicitation script contained three tokens of each type, and each type was read at the beginning, middle, and end of a block, which were randomized, in order to account for the possible effects of list intonation by speakers. The stimuli were produced in CV and VC order in order to determine whether or not the ordering of each type ([se] opposed to [es]) had any effect on the perception of the fricative by participants. Additionally, two types of front vowels, high tense [i] and mid tense [e], and two types of back vowels, high tense [u] and mid tense [o], were selected to be paired with each fricative.

All speakers were recorded with the audio analysis and recording program Praat, version 5.1.43 (Boersma and Weeink 2011), in a sound-attenuated booth in the Language Resource Center at the University of Georgia. A Shure SM58 vocal microphone was used for each participant. The microphone was connected to a Mac mini through the USBpre 1.5 microphone interface, and the recording volume was tested and adjusted for each participant.

After the three participants were recorded, the pitch and consonant duration of each token was extracted from its sound file and measured using Praat. The recordings from the participant with the most consistent pitch and consonant duration, a female speaker from northern Germany, were selected to be used as stimuli for the listening exercise. The participant whose recordings were selected for use as test stimuli was then recorded again in the same environment as the first recording. During the second recording the participant read from a revised elicitation script with only [ç] and [x] in order to obtain a greater sample of tokens of these types, since half of the tokens for [ç] and [x] were ungrammatical and a greater sample size was needed in order to set a target for the most palatal-like tokens of [ç] with back vowels and the most velar-like tokens of [x] with front vowels.

Following the second recording, each token was extracted from its carrier sentence, and the Center of Gravity (CoG) for each fricative was measured in Praat at 0.075 seconds into the beginning of the fricative using spectral slices which were .2 seconds long. CoG is a measurement of frequency divided by energy and averaged across the domain of the frequency. All CoG measurements were weighted by one, which corresponds to the absolute spectrum. CoG is particularly well suited to distinguishing fricatives from each other since one of the most prominent characteristics of a fricative is a relatively high frequency compared to other consonants. The average center of gravity for each fricative was then calculated. The token of each type with a center of gravity with the smallest minimum distance to the mean for its type was then selected for pairing in all same-different pairings as the most representative token of its type. The token with the second smallest minimum distance to the mean of its type was selected to pair with the first token in all same-same pairs. Thus, all same-same pairs contained two distinct tokens of the same type.

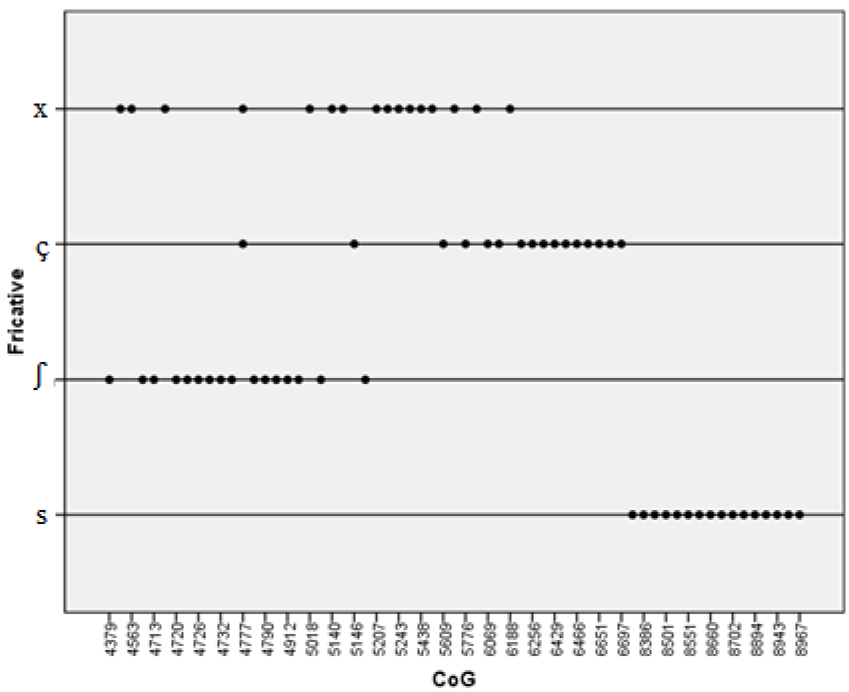


Figure 8. CoG measurements for each fricative token used as stimuli

As Figure 8 reveals, the only fricative that is clearly distinct from the other types is [s], while the other fricatives seem to be concentrated around certain CoG values, but have more overlap with one another than [s]. In order to confirm that the CoG value for each fricative could be used to as a distinguishing characteristic of the tokens, a one-way ANOVA was run on the CoG measurements for each fricative type selected to be used as stimuli based on its minimum distance to the mean CoG for its type (see Appendix A). Across fricative types, all fricatives were significant at $p < .001$, except for the pair [ʃ] – [x] which had a p-value of $F(3) = 320.6$, $p <$

.014, which shows that there is more overlap between the mean CoG of these two fricatives than the other fricatives, but that they are still significant based on an alpha level of .05.

The corresponding sound file of each token was then coded into an experiment procedure in the software program E-Prime v2.0 Professional along with the sound files for the practice procedure. The sound files for the practice procedure were produced by a native English speaker using four stops, [p], [b], [t], and [d], and one vowel, [a], in both CV and VC order.

CHAPTER 4

METHODOLOGY

Forty-two subjects participated in the listening experiment. The gender of participants was not recorded. Subjects in the listening experiment received the same screening questionnaire as those who participated in the production portion. Participants in the listening experiment would be deemed ineligible for the study if they were non-native speakers of English, native speakers of German, had any known difficulties concerning their hearing, or under eighteen. All participants who completed a screening questionnaire were eligible for the study.

Participants were recruited from undergraduate linguistics classes at the University of Georgia (Introduction to Language and Introduction to Phonetics/Phonology) through the distribution of an informational letter to instructors and an in-class announcement by the research team. Participants did not receive any compensation from the research team. Participants completed the experiment in a room paneled with acoustic foam in the Language Resource Center at the University of Georgia. The test room was equipped with two desktop computers running Windows 7 and E-Prime v2.0 Professional, and participants heard the stimuli through Sennheiser HD-280 Pro headphones. The listening experiment was comprised of two sections: a practice procedure and the main procedure. All participants heard the same stimuli, but the presentation of stimuli was randomized for each participant.

For both procedures, participants were instructed to respond only to the fricative sound and not the vowel, nor any possible difference in vowel pitch or length that they might perceive.

None of the stimuli used in either the practice procedure or the main experiment were embedded in static or any other noise. The stimuli in the practice procedure were varied to have intentionally different pitch levels and vowel durations in order to acquaint participants with any differences in pitch or vowel duration between stimuli within pairs that they might experience, as well as to train participants to focus their attention on the consonants. During the practice procedure, participants were also instructed on how to use the serial response box, where button 1 was labeled with ‘S’ for same responses and button 3 was labeled ‘D’ for different responses. Participants were also given feedback during the practice procedure stating whether or not their response was 'correct' or 'incorrect.' Prior to running the experiment, a ≤ 66% correct cutoff was established (no more than four incorrect pairs of the twelve tested), and any participants not meeting the cutoff standard in the practice procedure would not be included in the final results. Participants were not made aware of the cutoff point. All 42 participants were able to achieve a correct rate > 66%, and no results from any subject were omitted from the final analysis.

After completing the practice procedure, participants were given a short break before beginning the main experiment. The main experiment was comprised of 190 pairs of CV and VC one-syllable nonce words. During the main experiment each pair of stimuli (comprised of two tokens) matched in vowel and syllable order. All AX pairs were played in both orders of presentation (e.g. a participant would hear both [si] – [xi] and [xi] – [si] during the main procedure). Additionally, same pairs were weighted to occur three times during the procedure[6] in order to evenly distribute same pairs with different pairs. The results from the 42 participants were merged through E-Prime's data management system and exported to a spreadsheet in Excel, where the stimuli pairs (prime sound and a stimulus sound) were tagged for fricative type,

[6] Due to an error, one type, [us], was not weighted and only occurred as a same-same pair once, instead of twice.

syllable order, vowel (and vowel backness). The data were then exported to the statistical program SPSS (PASW 18). All descriptive statistics, ANOVAs, GLMs (general linear models), and logistic regressions were calculated with SPSS.

Initially, a time limit of 5000 ms for each test pair was set in the trial procedure; however, participants are unable to pause the experiment during a trial procedure in E-Prime, and in order to account for possible interruptions without stopping and re-administering the entire experiment, the time cap on response times was removed about one-third of the way through the experiment. Prior to unrestricting response times, 13 responses were not recorded by E-Prime due to the fact that the subject did not enter a response within 5000 ms. After the restriction on response times was lifted, subjects were still encouraged to respond to stimuli as quickly as possible; however, all responses were now recorded by E-Prime. In SPSS, all 46 responses with response times greater than 5000 ms were removed from the results. Responses that occurred 5000 ms after the presentation of stimuli had completed correctly discriminated the pairs at a rate of 69.6%, whereas subjects correctly discriminated the pairs at a rate of 90.3% when their responses occurred prior to the 5000 ms cutoff. The disparity between the percentages of correct discrimination for the responses before and after 5000 ms indicates that the subjects momentarily lost concentration or otherwise became distracted. A total of 59 responses out of 7,980 responses were either removed or not recorded based on response time.

A d-prime analysis was carried out using both SPSS and Excel. D-prime is a method of measuring the ability of participants to discriminate the presence of a signal opposed to the absence of signals which comes from Signal Detection Theory (see Macmillan & Douglas 2005). In a d-prime analysis, responses are divided into four different categories: hits, false alarms, misses and correct rejections. A hit occurs when the participant is presented with a signal, or in an AX discrimination task, a pair of different stimuli, and the participant correctly identifies the sounds as different. When the participant responds that a different pair is the same, their response is categorized as a false alarm. A miss occurs when a participant responds to a same pair, or non-signal, as different, and accordingly, a correct rejection is when the participant correctly identifies a same pair as same, or correctly rejects a non-signal.

A d-prime value is then calculated by multiplying the percentage of hits (where H = hits), by the standard score, or z-score and subtracting from it the percentage of false alarms (where FA = false alarms) multiplied by the z-score.

$$z(H) - z(FA) = d'$$

Figure 9. Formula for the calculation of d-prime

A minimal amount of overlap between hits and misses results in a higher d-prime. Using examples from Macmillan & Creelman (2005), if H=.99 and FA=.01 then d'=4.65, which means that participants were able to distinguish different stimuli quite easily. If H = FA, then d'= 0, and the normal distributions of hits and false alarms overlap almost entirely, which indicates that participants had difficulty discriminating the different stimuli from each other, as illustrated in the figures below.

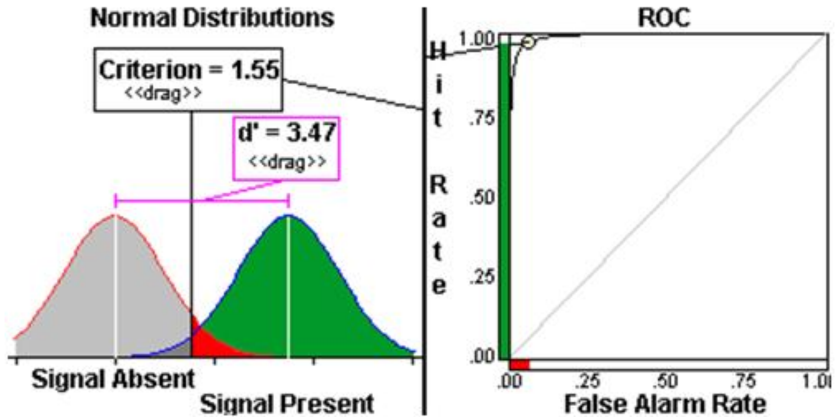


Figure 10. D-prime distribution for [ʃ] – [s] calculated from all pairs.[7]

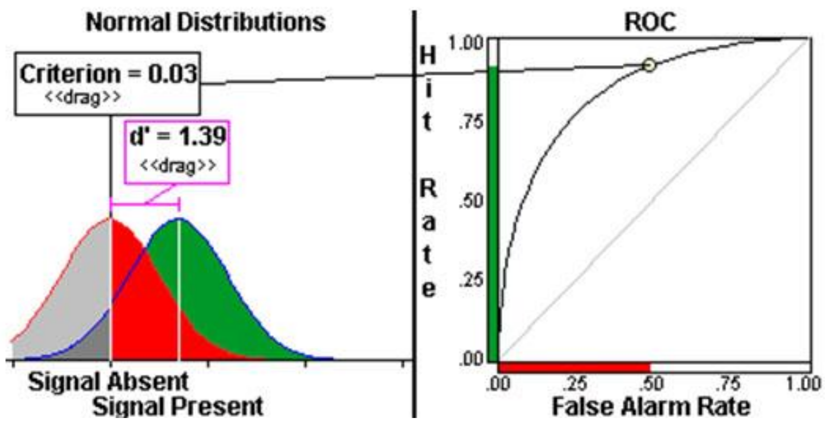


Figure 11. D-prime distribution for [ç] – [x] calculated for VC pairs.

Figures10 and 11 above illustrate the normal distribution of hits and false alarms and their overlap. Figure 10, which shows the d-prime of the pair [ʃ] – [s] shows that there is relatively little overlap between the two, which was typical of most of the fricative pairs tested, opposed to the [ç] – [x] pair in VC order, which had a noticeably smaller d-prime.

Additionally, the perceptual difference (PD) of each fricative pair was calculated in SPSS using formulas from Winters' (2003) dissertation on perception and place assimilation in English and Dutch. Winters (2003) follows previous work by Takane & Sargent (1983) and Nosofsky

[7] D-prime distributions were generated with WISE from Claremont Graduate University (http://wise.cgu.edu/sdtmod/index.asp).

(1992) which argue that RTs increase logarithmically as the participants' perception of the stimuli moves more toward the same – different decision threshold. This approach differs from previous work by Tserdanelis (2001) and Huang (2001), which used an analysis based on Shepherd (1978), stating that longer RTs correspond to a smaller PD between different pairs identified as "different" by participants and consequently, shorter RTs correspond to a larger PD. Winters (2003) finds this approach problematic because different pairs identified by participants as "same" are not accounted for in the analysis of PD. Using research by Podgorny & Garner (1979), which states that "same" responses are not only connected to "different" responses for different pairs, but the two are directly proportional, Winters (2003) introduces a model of PD centered upon the idea of a same – different threshold using the formulas given in Figure 12 and Figure 13 (*PD* = Perceptual Distance, *i* and *j* = any two fricatives). In Winters' model, a PD of 0 represents a pair of two sounds that cannot be distinguished as either the same or different, and in theory, the RT for such a pair would be infinite; thus, as the PD of a pair of fricatives (whether negative or positive) moves closer to 0, the perceptual distinctiveness of the two fricatives decreases and the RT is longer. Conversely, as the PD value moves away from 0, the fricative pair is more perceptually distinct and RTs are shorter.

PD for different pairs identified as "different" by participants is calculated with one over the natural logarithm (ln) of the RT, which inverts the order of the PD. The PD is inverted for pairs with a lower PD to correspond to a smaller perceptual distance, which in turn represents a longer RT. The PD for same pairs identified as "different" is the same as for different pairs, except that they are calculated to have negative values in order to fit Winters' model of PD.

$$PD_{ij} = \frac{1}{\ln\left(RT(D_{ij})\right)}$$

Figure 12. Formula for PD of different pairs identified as “different”

$$PD_{ij} = -\frac{1}{\ln\left(RT(S_{ij}\right)}$$

Figure 13. Formula for PD of different pairs identified as “same”

CHAPTER 5

RESULTS

The fricative pair [ç] – [x] was predicted to be the least perceptually distinctive of the fricative pairs tested because they are hypothesized to be the least contrastive of the fricative pairs tested based on Steriade's (2001) claim that assimilation is a type of contrast neutralization. Additionally, the contrast between [ç] and [x] was predicted to be affected by vowel backness and syllable order, since both of these factors are relevant to the distribution of dorsal fricatives within German words. For all statistical tests an alpha level of .05 was used.

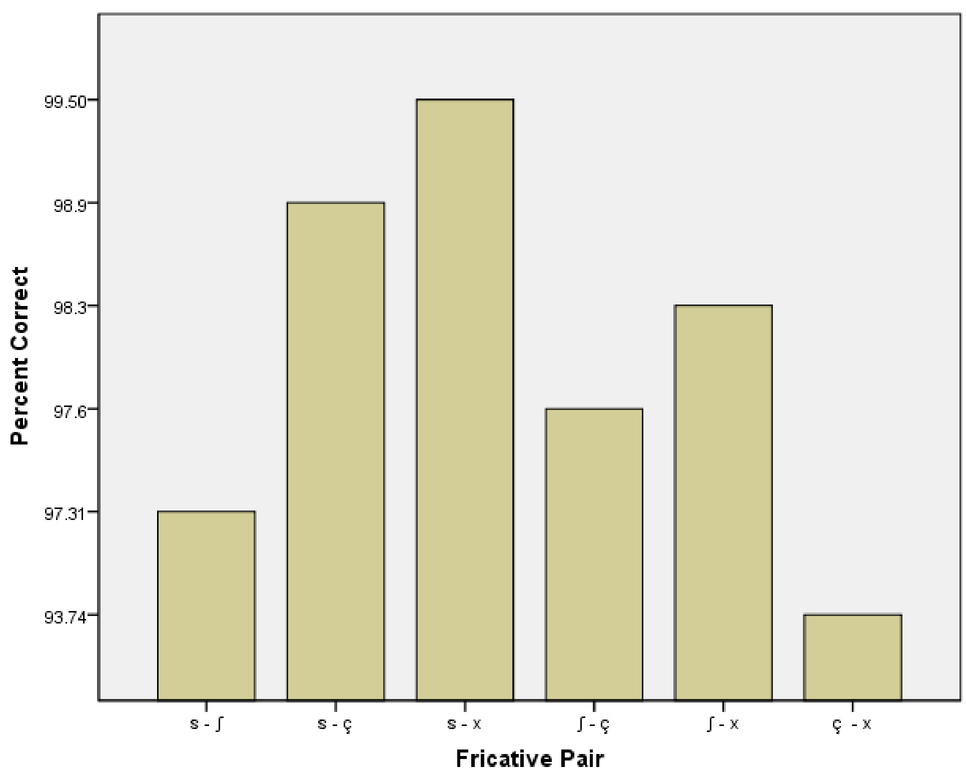


Figure 14. Percent Correct for each Fricative Pair.

Figure 14 above shows the rate of correct identification of different pairs as “different” by subjects. All pairs had correct identification rates greater than 90%, which is well above chance. The fricative pair with the highest rate of correct identification was [s] – [x] with 99.5%. [ç] – [x] had the lowest rate of correct identification with 93.74%. The remaining pairs were clustered between 97.31% and 98.9%.

A binary logistic regression was computed in SPSS as well. A binary logistic regression uses several predictor variables to interpret the probability of an outcome and create a statistical model of the analysis. The outcome of interest for this binary logistic regression was the probability of whether or not subjects correctly identified the pairs they responded to as “different” based on the predictor variables of subject, fricative pair, backness, and order. For the binary logistic regression, subjects were consolidated based on Fisher’s exact test, which is a test of statistical significance commonly used with categorical data, which was calculated for 95 possible responses. Using Fisher’s exact test, it was determined that one to four incorrect responses from a single subject was not significant, and more than five incorrect responses from one participant was statistically significant. Of the subjects who participated in the listening experiment, 36 incorrectly identified four or fewer different pairs as “same.” These 36 subjects were grouped together into one “cover” subject, while the remaining six subjects (who incorrectly identified five or more different pairs as “same”) remained as individual subjects per the advice of the University of Georgia Statistical Consulting Center. The subjects who performed poorly at a statistically significant level remained in the analysis because there were no indications that their responses were invalid.

A total of 13 predictor variables were used in the calculation of the binary logistic regression. Six of the predictor variables were individual subjects with the “cover” subject group set as the baseline. Five of the predictor variables were fricative pairs. The fricative pair [ç] – [x] was set as the baseline for fricative pairs within the model. Syllable order comprised one predictor variable with VC order as the baseline. The last predictor variable was vowel backness with [+back] vowels set as the baseline.

When all 13 independent variables are entered into the model, they significantly predict whether or not a different pair was identified as "same" or "different" by subjects, $\chi^2 = 162.27$, $df = 13$, $N = 3963$, $p < .001$. Backness was the only predictor variable which was not statistically significant at the .05 level when all 13 variables were examined together ($p = .206$).

Fricative pair as a whole is statistically significant ($p < .001$), and each possible combination of fricative pairs is significant ($p \leq .001$) when contrasted against the baseline pair [ç] – [x].

Variable	**B**	**SE**	**Odds Ratio**	***p***
s – ʃ	.96	.30	2.61	.001
s – ç	1.96	.42	7.08	.000
s – x	2.82	.61	16.85	.000
ʃ - ç	1.03	.31	2.80	.001
ʃ - x	1.49	.35	4.43	.000

Table 1. Logistic Regression Predicting Effect of Fricative Pair on correct identification of different pairs compared to [ç] – [x].

The odds ratios for each fricative pair are based on [ç] – [x] as the baseline. Table 1 above shows that the pair [s] – [x] has the highest odds ratio, which suggests that the odds of correctly identifying a different pair are vastly increased when a subject hears this pair opposed to [ç] – [x]. All other fricative pairs also show a higher odds ratio for correct identification than [ç] – [x], though none quite as dramatically as [s] – [x].

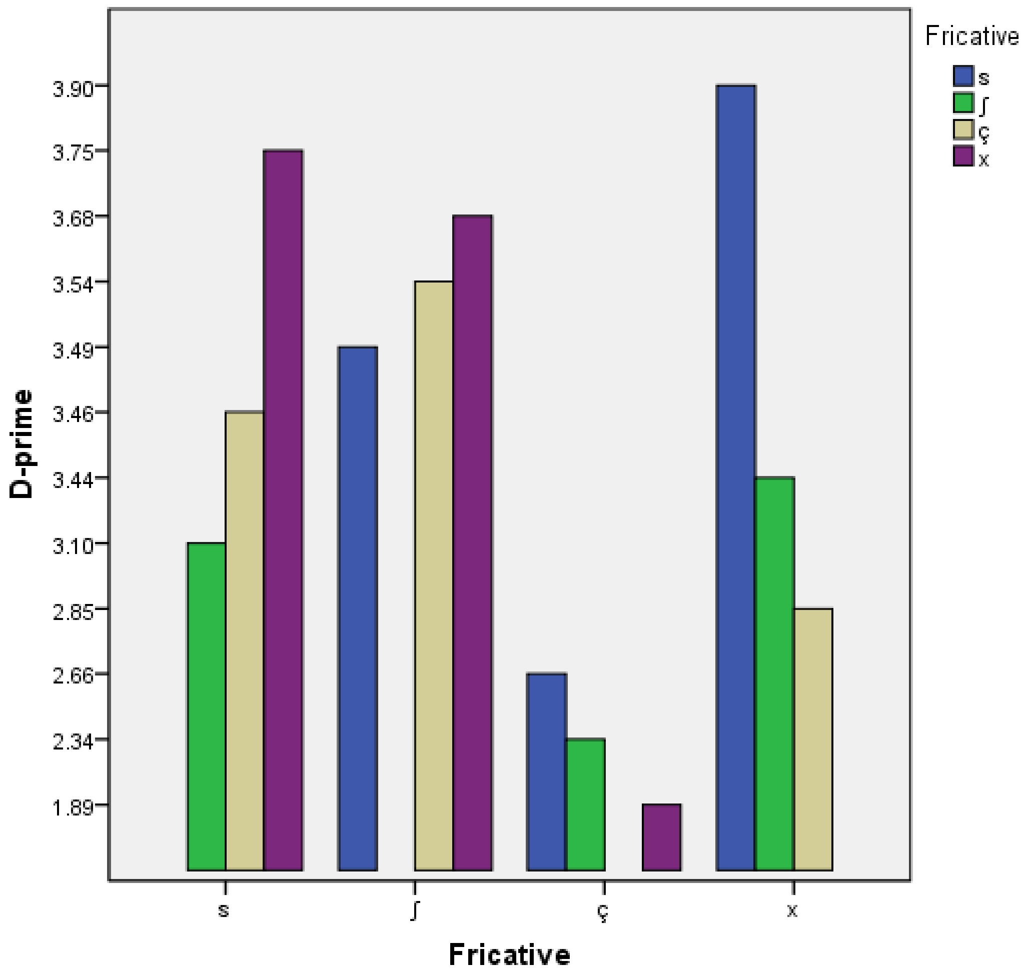


Figure 15. D-prime for all fricatives[8]

The next statistical analysis applied to the data was a d-prime analysis using data from different pairs correctly identified as "different" (or hits, in Signal Detection Theory terminology), and same pairs incorrectly identified as "different" (which are also known as false alarms). As Figure 15 above shows, [ç] has the three lowest d-prime values of the four fricatives when the fricatives are analyzed in all syllable orders (CV and VC) and with both front and back vowels. The low d-prime values can be attributed to the higher rate of false alarms present

[8] The fricative on the x-axis represents the fricative for which the rate of false alarms was calculated. The fricative on the column panel is the fricative for which the rate of hits was calculated. Because false alarms are based on the same pairs identified as "different" by participants, as pair such as [s] – [x] can have different d-prime values depending on the fricative for which false alarms were calculated.

within same pairs of [ç] opposed to the other three fricatives. Examining the chart above, the pair with the lowest d-prime value is [ç] – [x] with 1.89, opposed to [x] – [s], which is the pairing with the highest d-prime value with 3.9.

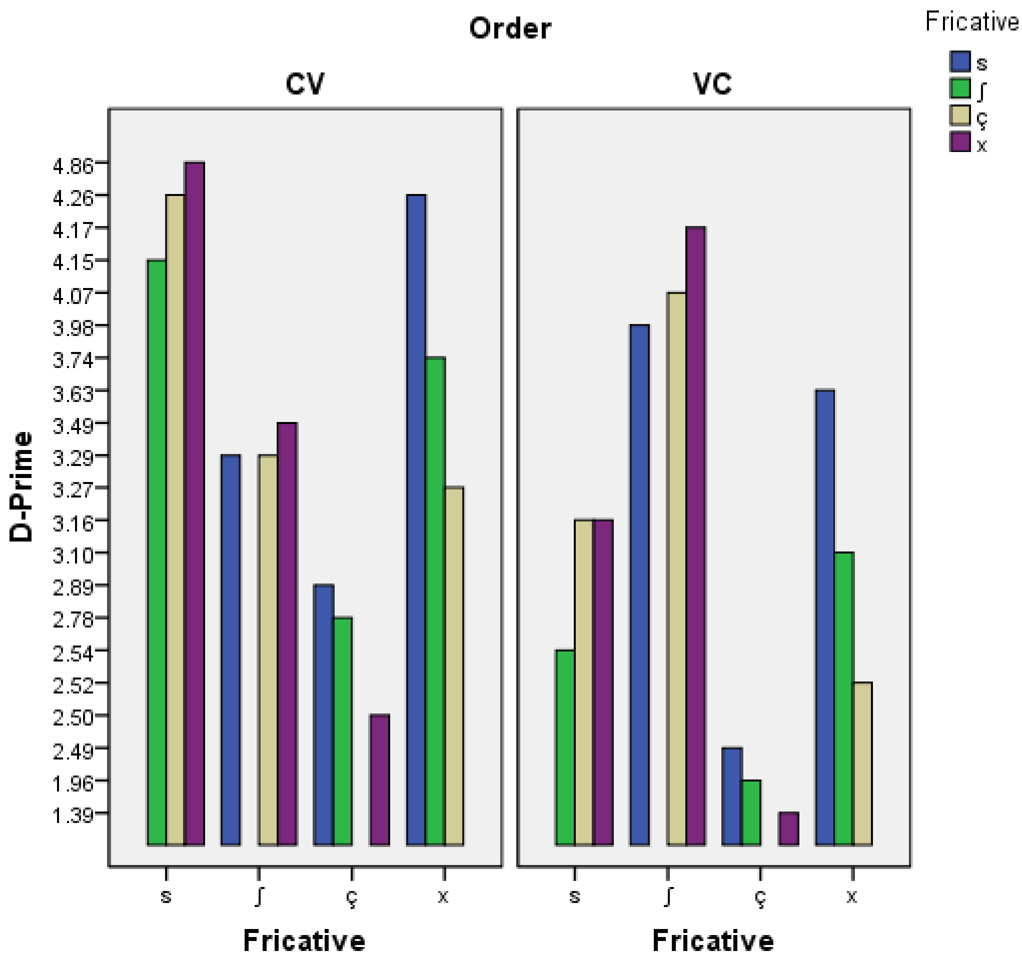


Figure 16. Results of d-prime analysis and interaction between fricative and syllable order

The same procedure was then carried out for the d-prime analysis of all fricative pairs taking syllable order into account as seen in Figure 16 above. Examining d-prime values based on differences in syllable order, which is a statistically significant predictor variable in the binary logistic regression, shows quite a bit of variability in the distinctness of signals of each fricative in CV and VC order, respectively. As a whole, the d-prime values for CV pairs are higher than

VC; however, there are a few notable exceptions. [ʃ] has higher d-prime values for all fricatives in VC order than CV, and [s] has lower d-prime values for all fricatives in VC order. D-prime values for both [ç] and [x] are lower in VC order than CV. With the exception of [ʃ], VC order seems to diminish the ability of participants to perceive the relevant signals.

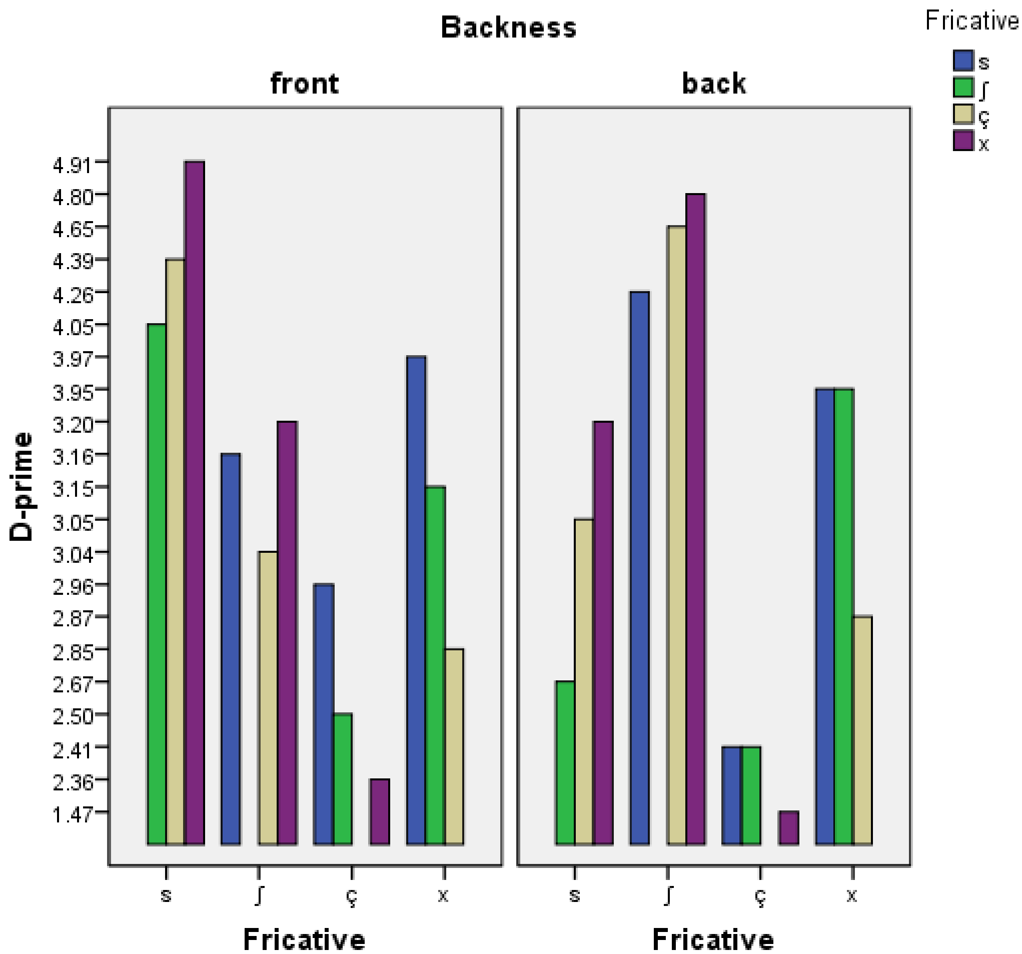


Figure 17. Results of d-prime analysis of the interaction between fricative and vowel backness

A d-prime analysis was then calculated for all fricative pairs using the same procedure and taking vowel backness into account. As Figure 17 above shows, there are some differences in the perception of each fricative in the two different environments. Based on the binary logistic regression discussed earlier, vowel backness alone is not a statistically significant predictor variable; however, the univariate analysis of varience conducted on RTs and subject responses, which will be discussed later in this section, shows the interation between vowel backness and fricative pair to be statistically significant, F (5, 1) =3.2, p = .007.

The d-prime values of [s] were higher when [s] was paired with front vowels, and this was particularly evident when the d-prime of the pair [s] – [ʃ] with a a front vowel, d'= 4.05, was compared to [s] – [ʃ] with a back vowel, d'= 2.67. The d-prime values of [ʃ] with back vowels were consistantly higher than [ʃ] with front vowels for all fricatives. Conversly, the d-prime values of [ç] were higher with front vowels than with back vowels for all fricative pairs. The d-prime value of [x] with [s] was higher with front vowels, however, the pairs [x] – [ʃ] and [x] – [ç] had higher d-prime values with back vowels.

As a d-prime analysis allows for the perception of fricatives to be modeled based on the responses of participants, specifically the responses which have been categorized as hits and misses, respectively, the model for calculating PD as discussed in Winters (2003) provides a statistical model for representing responses that would be deemed hits or misses in the terminology of signal detection theory, which would otherwise be known as a “different” response to different stimuli and a “same” response to different stimuli, respectively. Importantly, the PD model allows for the inclusion of RT within the statistical model as was discussed in more detail in Chapter 4.

The PD for the hits was calculated in SPSS using the formula in Figure 8 and the PD for misses was calculated using the formula in Figure 9. A univariate analysis of variance, which is a type of general linear model (GLM), for PD was calculated in SPSS with PD as the dependent variable and the fricative pair (coded as “combo”), vowel backness (coded as “backness”), and syllable order (coded as "order') as fixed variables. Subject was also entered as a fixed variable in order to serve as a blocking factor in order to incorporate the correct degrees of freedom. The GLM for PD was re-calculated until the most parsimonious model was achieved (see Appendix A for tests of between-subjects effects).

As fixed variables, both fricative pair, F (5) = 2.97, p = .011, and order, F (1) = 17.45, p < .001, are statistically significant. Backness alone, however, is not statistically significant, F (1) = 3.51, p = .06. The interaction between fricative pair and backness, as stated previously, is statistically significant, F (5, 1) =3.2, p = .007. The interaction between fricative pair and subject, F (5, 41) = 1.28, p = .006, and order and subject, F (1, 41) = 1.398, p =.048, are both statistically significant as well. A Tukey HSD post-hoc test was conducted on the fricative pairs, and only one set of pairs, [ʃ] – [x] against [ç] – [x], had a statistically significant difference in mean PD (14, p =.016).

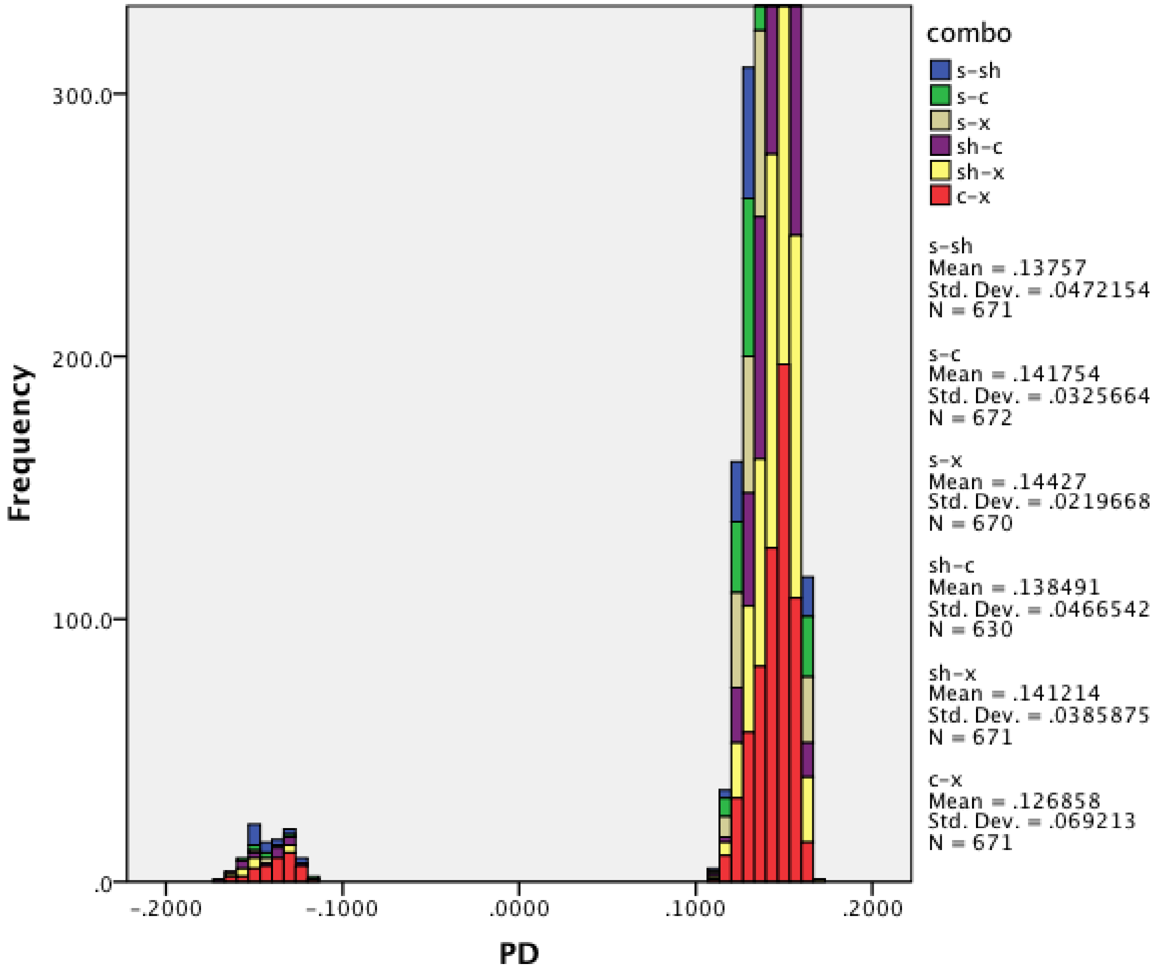


Figure 18. PD and Fricative Pair

Figure 18 above plots the PD of each fricative pair with the PD of correctly identified different pairs to the right of .0, which represents the same – different threshold, and the PDs of incorrectly identified different pairs to the left of the same – different threshold. From Figure 18, one can also see that "different" pairs were correctly identified as "different" at a much higher frequency than incorrect "same" identification. Despite the much higher frequency of correct identifications, one can still see the correlation between the distribution curve of different pairs identified as "different" and different pairs identified as "same."

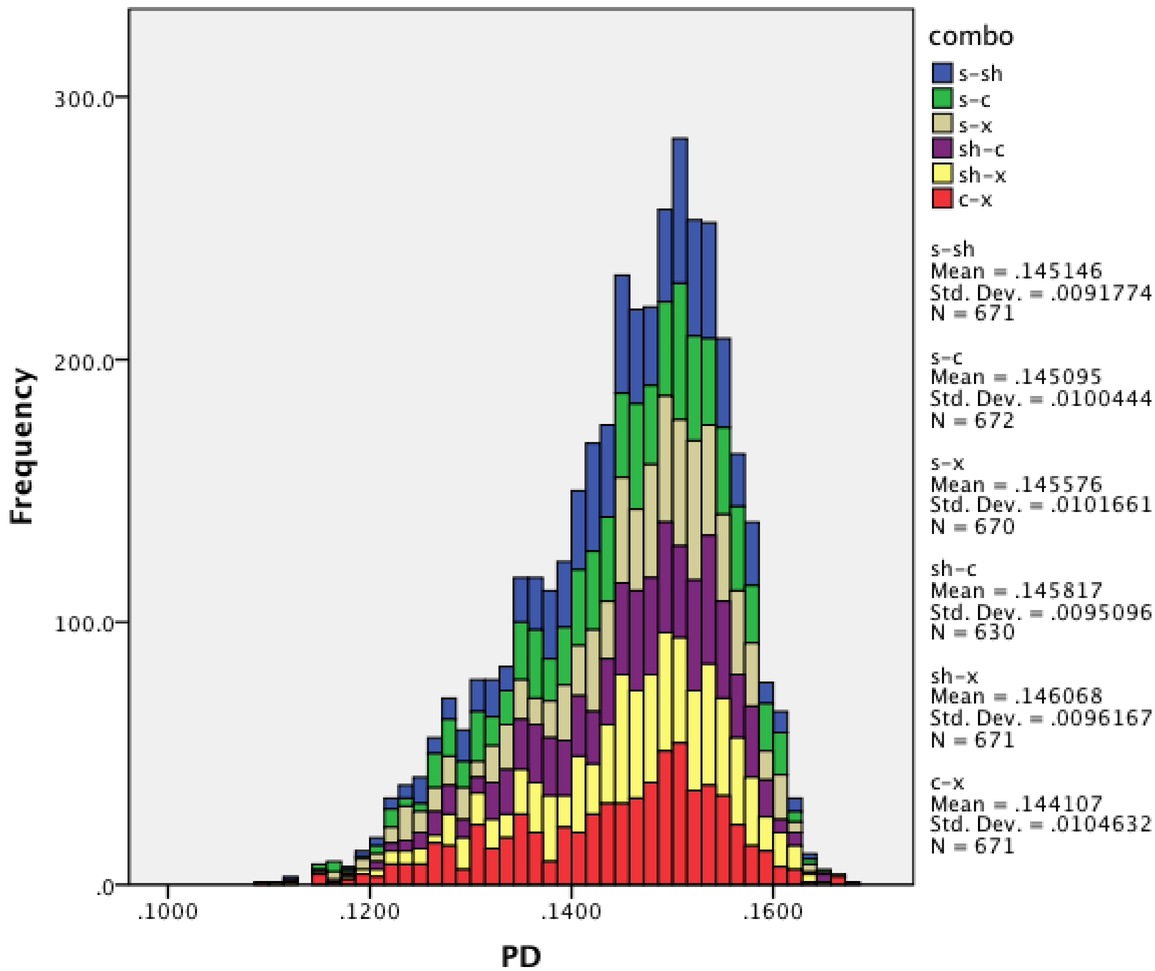


Figure 19. PD of different pairs identified as “different”

Examining the histogram of the PD of correctly identified different pairs in Figure 19 above reveals that the distribution of PD for each fricative pair is fairly similar, and all of the pairs appear to skew to the right.

CHAPTER 6

DISCUSSION

The high percentage of correct responses for different fricative pairs identified as "different" by subjects (all different fricative pairs were correctly identified > 90%) was unsurprising, since the fricative pairs were not embedded in noise or static to make their identification more difficult or obscured for the subjects. The fricative pair with the lowest rate of correct identification, [ç] – [x], 93.7%, was also expected as it was hypothesized as the pair with the lowest perceptual distinctiveness. The pair with the highest rate of correct identification, [s] – [x], 99.5%, was also unsurprising, yet still intriguing, since the articulations of the two fricatives are the farthest from each other. The percentage of correct identification of different pairs is not a definitive answer on the perceptual distinctiveness of the pair [ç] – [x], and the fricatives individually; however, it does provide an initial indication that the pair [ç] – [x] is problematic.

The binary logistic regression conducted on participant responses to different pairs supports the initial assumptions of the rates of correct identification. Of particular interest, when [ç] – [x] is used as the baseline pair, all other fricative pairs are statistically significant as predictor variables, which means that [ç] – [x] is the pair least likely to predict whether or not participants will correctly identify different pairs as "different," indicating that participants had the most difficulty discriminating these fricatives from each other.

Of particular note is that the percentage of correct identification only takes different pairs that were identified as "different" into account. Same pairs that were identified as "different" are also important to consider because they can contribute additional information about the relative ease of perception, or the ease of discrimination, of stimuli by participants as seen through the results of the binary logistic regression and the d-prime analysis. Additionally, each fricative needs to be examined independently from the pairings in which they were tested, which is one of the reasons a d-prime analysis is useful in the information that it provides. The d-prime analysis can also broaden the scope of the statistical models used thus far by indicating whether or not the pair [ç] – [x] is especially problematic, or if either fricative is less perceptually distinct than the other fricatives on its own.

Initial indications after examining Figure 15 lead me to conclude that while the d-prime of the pairs [ç] – [x], *d'* = 1.89, and [x] – [ç], *d'* = 2.85, display less perceptual distinctiveness than several other pairs, the high false alarm rates of [ç] cause it to have less perceptual distinctiveness in several combinations, unlike [x]. [ç] has a false alarm rate of 48% when paired with back vowels, compared to the false alarm rate of 23% with front vowels. [x], on the other hand, has a false alarm rate of 11% when paired with front vowels and 7% when paired with back vowels.

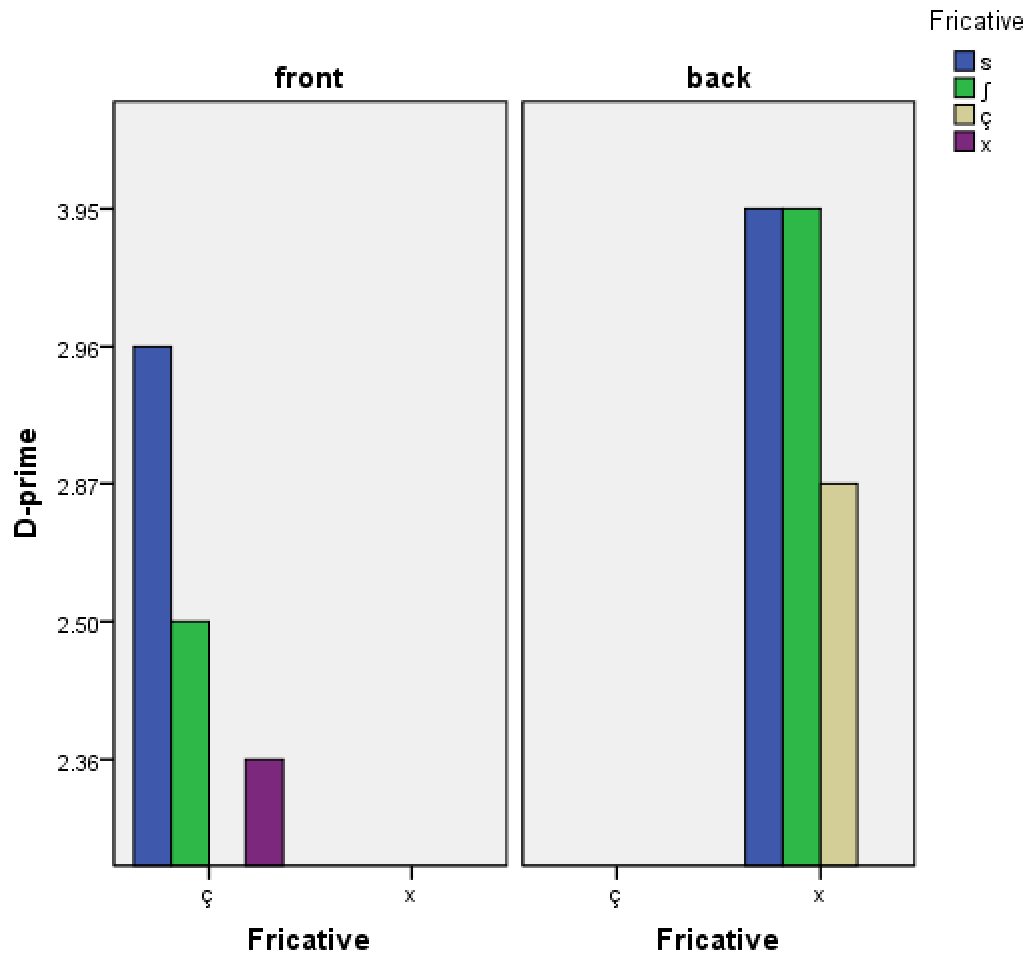


Figure 20. Results of a d-prime analysis of [ç] with front vowels and [x] with back vowels.

Even with front vowels, [ç] has higher false alarm rates than [x], which indicates that [ç] is less perceptually distinct for participants as demonstrated by Figure 20, which shows the d-prime values of [ç] and [x] in naturalistic pairings, with front vowels and back vowels, respectively.

The GLM calculated for PD does not add any additional information to the perception of individual fricatives; however, it does show that vowel backness combined with fricative pair is statistically significant, while backness alone is not, which I can attribute to the PD of [ç] – [x] with back vowels deviating from the model. The GLM also shows that syllable order is statistically significant in relation to PD, which is of interest since only [ç] can occur word initially. Interestingly, the d-prime of [ç] in VC syllables is less than [ç] in CV syllables, yet a similar decrease of d-prime values is found in VC syllables with [x], even though [x] does not occur word initially. The increased perceptual distinctiveness of CV pairs is not entirely surprising though, since CV syllables are universally less marked. The only fricative that demonstrated increased perceptual distinctiveness in VC order, as based on d-prime, was [ʃ]. Returning to [ç] and [x], the decreased perceptual distinctiveness of both fricatives in VC order does not contribute any information to whether or not there is a perceptual motivation causing initial [ç] to be more common than initial [x].

Of the statistical models that were used, Winters' measurement of PD brought the least amount of information to bear on the question of which dorsal fricative is underlying, as well the perceptual distinctiveness of individual fricatives. As seen in Figure18, and in particular with Figure 19, the PD of each fricative pair is distributed nearly identically. This seems quite unusual based on the results of the binary logistic regression and d-prime analysis, which showed that the pair [ç] – [x] is the least perceptually distinctive, and accordingly, should be skewed left toward the same – different threshold, and raises some concerns about the accuracy of PD. Thus, either RT cannot inform our understanding of whether or not participants had difficulty with a particular sound or pair, or RT alone does not reveal the distinctiveness of sounds along a continuum of perceptual distance. One last concern regarding PD is that it does not distinguish between the decision-making process of participants and the relative perceptual distinctiveness of the stimuli. D-prime, contrastingly, accounts for both the decision-making process of participants, as well as their response to the stimuli. Therefore, in comparison to the binary logistic regression and the d-prime analysis, the model of PD did not appear to provide entirely accurate results regarding the perceptual distinctiveness of the fricative pairs that were tested.

CHAPTER 7

CONCLUSION

This study sought to investigate dorsal fricative assimilation in German, and more specifically, evidence for which of the two dorsal fricatives in German is underlying, by using perceptual data gathered from English speakers unfamiliar with dorsal fricatives. The dorsal fricatives [ç] and [x] were tested in both natural and unnatural pairings in order to understand the perception of [ç] and [x] when contrasted with each other and individually. The fricative pair [ç] – [x] was predicted to have the smallest perceptual contrast of all other combinations of voiceless dorsal and coronal fricatives in Standard German. The Dispersion Theory of Contrast (Flemming 2002), as well as the idea that assimilation is a type of contrast neutralization (Steriade 2001) formed the guiding theoretical principles of the design of the listening experiment, and contributed to the initial hypothesis that [ç] and [x] do not form a contrast in German because they are not strongly distinctive from a perceptual standpoint.

Based on the results of a binary logistic regression and d-prime analysis of the results, the data supported the initial hypothesis that [ç] and [x] are not strongly contrastive. Additionally, the PD (Winters 2003) of the data was calculated; however, the data challenges the accuracy of Winters' model due to the incongruity of its results with those from the other statistical models. Although the process of German dorsal fricative assimilation is not controversial, unlike the debate surrounding which dorsal fricative is underlying, this information provides perceptual information on why this assimilation is a productive process in German. Furthermore, it provides additional support for the claim that speech perception can inform our understanding of phonological processes. One particular piece of evidence that can be used to support this claim is that the pair [ç] – [x] is the least likely to predict whether or not a participant will correctly identify a different pair as “different.” Similar rates of confusability are not seen among any of the other fricative pairs that were tested, which supports the idea that these pairs are strongly contrastive, opposed to the pair [ç] – [x].

Returning to the question of which dorsal fricative is underlying in German, it is reasonable to assume that the most perceptually distinctive, and thus, contrastive, dorsal fricative is underlying. Based on the statistical models using subject responses, the data indicate that from a perceptual standpoint [x] is a stronger candidate as the underlying dorsal fricative. The most conclusive evidence supporting [x] as the underlying dorsal fricative comes from the d-prime analysis. In particular, the d-prime of [x] is fairly similar to that of [s] and [ʃ], even when [x] is paired with front vowels, whereas the signal detection of [ç] is much weaker, as demonstrated by its high rate of false alarms and lower d-prime. While the d-prime of [x] was nearly as high when paired with back vowels as with front vowels, which demonstrates strong signal detection, the d-prime of [ç] was notably lower when it was paired with back vowels. This was particularly surprising, because [ç] is argued to be underlying because it has a wider distribution than [x].

I propose that additional research needs to be done to study the acoustic characteristics of the dorsal fricatives, and to investigate further into Stevens’ claim that the lowest resonance peak of [ç] correlates to F3 of the preceding vowel, and how the acoustic qualities of [ç] with a rounded vowel compare to [x] in the same environment. F3 distinguishes several pairs of front vowels in German, such as [i] and [y], which are only differentiated through rounding. Based on the results of this experiment, the perceptual distinctiveness of [x] with front vowels does not differ greatly from [x] with back vowels, whereas the pairing of [ç] with back vowels sharply decreases the perceptual distinctiveness of [ç]. A future experiment focusing on the effect of rounding on the perception of German dorsal fricatives could potentially expand our understanding of the correlation between formants and the peak resonance frequencies of dorsal fricatives. Additionally, such a study could further clarify the results of this study, which suggest that with unrounded front vowels [x] is more perceptually distinctive than [ç], and whether or not the same finding holds true with rounded front vowels.

Although this study cannot conclusively demonstrate which dorsal fricative is underlying, it can contribute further evidence to the claim that perception interacts with phonology, as well as provide initial indications that [x] is more perceptually distinctive, and thus, more likely to be underlying. Furthermore, the use of native English speakers, who had little to no previous exposure to dorsal fricatives, to obtain a more universal perspective on the perception of German dorsal fricative assimilation also proved to be successful as evidenced through the high rates of correctly identified "different" pairs other than [ç] – [x]. Finally, this study has shown that the elimination of a weak phonetic contrast through assimilation, such as the lack of a contrast between [ç] and [x] in German, can be attributed to perceptual pressures.

REFERENCES

Barbour, S. & Stevenson, P. (2003). Variation in German: a critical approach to German sociolinguistics. New York: Cambridge University Press.

Boersma, P. & Weenink, D. (2011). Praat: doing phonetics by computer [Computer program]. Version 5.1.43, retrieved 11 May 2011 from http://www.praat.org/.

Borowsky, T. (1993). On the Word level. In S. Hargus & E. M. Kaisse (eds.) Studies in Lexical Phonology. San Diego: Academic Press. 199-234.

Dresher, B. E. (2009). The contrastive hierarchy in phonology. Cambridge: Cambridge University Press.

Flemming, E.S. (2002). Auditory representations in phonology. New York: Routledge.

Gordon, Matthew (2002). A phonetically driven account of syllable weight. Language 78.1. 51-80.

Gordon, M. & Barthmaier, P. & Sands, K. (2003). A cross-linguistic acoustic study of voiceless fricatives. Journal of the International Phonetic Association. 32. 141-174.

Gussmann, E. (2002). Phonology: Analysis and Theory. New York: Cambridge University Press.

Hall, T.A. (1992). Syllable structure and Syllable-related processes in German. Tübingen: M. Neimeyer.

Hall, T.A. (1997). The Phonology of Coronals. Amsterdam: J. Benjamins.

Huang, T. (2001). The interplay of perception and phonology in tone 3 sandhi in Chinese Putonghua. Ohio State University Working Papers in Linguistics. 55. 23-42.

Jensen, John T. (2000). Against Ambisyllabicity. Phonology. 17. 187-235.

Jongman, A., Wayland, R. & Wong, S (2000). Acoustic characteristics of English fricatives. Journal of the Acoustical Society of America. 108. 1252-1263

Kaplan, A. (2009). Perceptual Pressures on Lenition. LSA Annual Meeting. Handout.

Kingston, J (2007). The phonetics-phonology interface. P. de Lacy (Ed.), Handbook of Phonology, (pp. 435-456), Cambridge, UK: Cambridge University Press

Kohler, K. (1990). “Comment on German.” Journal of the International Phonetic Association. 20.

Lindblom, B. & Sundberg, J. (1971). Acoustical consequences of lip, tongue , jaw and larynx movement. Journal of the Acoustical Society of America. 50. 1166-1179.

Macmillan, N.A. & Creelman, C. D. (2005). Detection Theory: A User's Guide (2nd edition). Mahwah, New Jersey: Lawrence Erlbaum Associates, Publishers.

Mann, V.A. (1986). Distinguishing universal and language-dependent levels of speech perception: evidence from Japanese listeners’ perception of English “l” and “r.” Cognition. 24. 169-196.

Merchant, J. (1996). Alignment and fricative assimilation in German. LI. 27. 709-719.

Nosofsky, R.M. (1992). Similarity scaling and cognitive process models. Annual Review of Psychology. 43. 25-53.

Padgett, J. & Zygis, M. (2007). The evolution of sibilants in Polish and Russian. Journal of Slavic Linguistics. 15. 291-324

Padgett, J. & Zygis, M. (2010). A perceptual study of Polish fricatives and its relation to historical sound change. Journal of Phonetics 30. 207-226

Podgorny, P., & Garner, W. (1979). Reaction time as a measure of inter- and intraobject visual similarity: Letters of the alphabet. Perception & Psychophysics. 26. 37-52.

Psychology Software Tools, Inc. (2011). E-PrimeTM software . Pittsburgh, USA: www.pstnet.com/eprime

Rauch, I. (2008). The phonology/paraphonology interface and the sounds of German across time. New York: Peter Lang.

Riordan, C. (1977). Control of vocal-tract length in speech. Journal of the Acoustical Society of America.

Russ, C. (1978). Historical German Phonology and Morphology. Oxford: Clarendon Press.

Russ, C. (1982). Studies in Historical German Phonology. Berne: Peter Lang.

Shepherd, R.N. (1978). The circumplex and related topological manifolds in the study of perception. Theory Construction and Data Analysis in the Behavioral Sciences. S.Shye (Ed.). San Francisco: Jossey-Bass.

Steinberg, J., Truckenbrodt, H. & Jacobsen, T. (2010). Activation and application of an obligatory phonotactic constraint in German during automatic speech processing is revealed by human event-related potentials. International Journal of Psychophysiology. 77. 13-20.

Stevens, K.N. (1989). On the quantal nature of speech. Journal of phonetics. 17, 3-46.

Steriade, D. (2001). The role of speech perception in phonology. E. Hume & K. Johnson (Eds.) Directional asymmetries in place assimilation: a perceptual account. (pp. 219 – 250). San Diego: Academic Press.

Takane, Y. and Sargent, J. (1983). Multidimensional scaling models for reaction times and same-different judgments. Psychometrika. 48. 393-423.

Trubetzkoy, N.S. (1969). Principles of Phonology. C. Baltaxe (tr.). Berkeley and Los Angeles: University of California Press.

Tserdanelis, G. (2001). A perceptual account of manner dissimilation in Greek. *Ohio State* University Working Papers in Linguistics. 55. 172-199.

Weber, A. (2001). Help or hindrance: how violation of different assimilation rules affects spoken -language processing. Language and Speech. 44. 95-118.

Winters, S.J. (2003). Empirical investigations into the perceptual and articulatory origins of cross-linguistic asymmetries in place assimilation. PhD Dissertation. The Ohio State University.

APPENDIX A: STATISTICS OUTPUT FROM SPSS

Multiple Comparisons

CoG

Tukey HSD

(I) Fricative	(J) Fricative	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
s	sh	3875.438*	137.054	.000	3513.27	4237.61
	c	2535.688*	137.054	.000	2173.52	2897.86
	x	3446.250*	137.054	.000	3084.08	3808.42
sh	s	-3875.438*	137.054	.000	-4237.61	-3513.27
	c	-1339.750*	137.054	.000	-1701.92	-977.58
	x	-429.188*	137.054	.014	-791.36	-67.02
c	s	-2535.688*	137.054	.000	-2897.86	-2173.52
	sh	1339.750*	137.054	.000	977.58	1701.92
	x	910.563*	137.054	.000	548.39	1272.73
x	s	-3446.250*	137.054	.000	-3808.42	-3084.08
	sh	429.188*	137.054	.014	67.02	791.36
	c	-910.563*	137.054	.000	-1272.73	-548.39

*. The mean difference is significant at the 0.05 level.

Table 2. ANOVA of CoG measurements for each fricative type.

Tests of Between-Subjects Effects

Dependent Variable:PD

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.151[a]	299	.001	8.929	.000
Intercept	81.198	1	81.198	1.437E6	.000
combo	.001	5	.000	2.974	.011
order	.001	1	.001	17.448	.000
backness	.000	1	.000	3.513	.061
Subject	.130	41	.003	56.187	.000
combo * Subject	.015	205	7.202E-5	1.275	.006
order * Subject	.003	41	7.898E-5	1.398	.048
combo * backness	.001	5	.000	3.208	.007
Error	.201	3566	5.650E-5		
Total	82.275	3866			
Corrected Total	.352	3865			

a. R Squared = .428 (Adjusted R Squared = .380)

Table 3. The most parsimonious model of tests of between-subjects effects from a Univariate analysis of variance of Perceptual Distance.

APPENDIX B: PRODUCTION AND TESTING MATERIALS

"The Perception of Dorsal Fricatives by Native Speakers of English"

Screening Questionnaire

Circle 'yes' or 'no'

Are you 18-year-old or older?	Yes	No
Do you have any known hearing problems?	Yes	No
Are you a native speaker of English?	Yes	No
Are you a native speaker of German?	Yes	No

Elicitation Script:

“The Perception of German Dorsal Fricatives by Native Speakers of English”

Elicitation script:

Dear Participant,

Please say the following sentences below as naturally as possible. Because this study is concerned with two sounds in German which are spelled with the same letters, the nonce words (Platzhalter) will be spelled using the International Phonetic Alphabet (IPA). Each nonce word will be placed within the same carrier sentence: *Ich hab' X gesagt.* 'I have said X.'

The following IPA characters correspond to the following sounds in German (in bold):

[s] as in 'fu**ß**' *foot*
[ʃ] as in '**Sch**uh' *shoe*
[ç] as in 'i**ch**' *I*
[x] as in 'Bu**ch**' *book*

[i] as in 'S**ie**' *You*
[u] as in 'f**u**ß' *foot*
[e] as in '**Eh**re' *honor*
[o] as in '**oh**ne' *without*

Please say each sentence below. Some of these sound combinations do not occur in German. Please try to pronounce them as naturally as possible.

Ich hab’ [si] gesagt.
Ich hab’ [su] gesagt.
Ich hab’ [se] gesagt.
Ich hab’ [so] gesagt.

Ich hab’ [ʃi] gesagt.
Ich hab’ [ʃu] gesagt.
Ich hab’ [ʃe] gesagt.
Ich hab’ [ʃo] gesagt.

Ich hab’ [çi] gesagt.
Ich hab’ [çu] gesagt.
Ich hab’ [çe] gesagt.
Ich hab’ [ço] gesagt.

Ich hab’ [xi] gesagt.
Ich hab’ [xu] gesagt.
Ich hab’ [xe] gesagt.
Ich hab’ [xo] gesagt.

Ich hab’ [is] gesagt.
Ich hab’ [us] gesagt.
Ich hab’ [es] gesagt.
Ich hab’ [os] gesagt.

Ich hab’ [iʃ] gesagt.
Ich hab’ [uʃ] gesagt.
Ich hab’ [eʃ] gesagt.
Ich hab’ [oʃ] gesagt.

Ich hab’ [iç] gesagt.
Ich hab’ [uç] gesagt.
Ich hab’ [eç] gesagt.
Ich hab’ [oç] gesagt.

Ich hab’ [ix] gesagt.
Ich hab’ [ux] gesagt.
Ich hab’ [ex] gesagt.
Ich hab’ [ox] gesagt.

Ich hab’ [xo] gesagt.
Ich hab’ [xi] gesagt.
Ich hab’ [xu] gesagt.
Ich hab’ [xe] gesagt.

Ich hab’ [so] gesagt.
Ich hab’ [si] gesagt.
Ich hab’ [su] gesagt.
Ich hab’ [se] gesagt.

Ich hab’ [ço] gesagt.
Ich hab’ [çi] gesagt.
Ich hab’ [çu] gesagt.
Ich hab’ [çe] gesagt.

Ich hab’ [ʃo] gesagt.
Ich hab’ [ʃi] gesagt.
Ich hab’ [ʃu] gesagt.
Ich hab’ [ʃe] gesagt.

Ich hab’ [ox] gesagt.
Ich hab’ [ix] gesagt.
Ich hab’ [ux] gesagt.
Ich hab’ [ex] gesagt.

Ich hab’ [os] gesagt.
Ich hab’ [is] gesagt.
Ich hab’ [us] gesagt.
Ich hab’ [es] gesagt.

Ich hab’ [oç] gesagt.
Ich hab’ [iç] gesagt.
Ich hab’ [uç] gesagt.
Ich hab’ [eç] gesagt.

Ich hab’ [oʃ] gesagt.
Ich hab’ [iʃ] gesagt.
Ich hab’ [uʃ] gesagt.
Ich hab’ [eʃ] gesagt.

Ich hab’ [çi] gesagt.
Ich hab’ [çu] gesagt.
Ich hab’ [çe] gesagt.
Ich hab’ [ço] gesagt.

Ich hab’ [ʃi] gesagt.
Ich hab’ [ʃu] gesagt.
Ich hab’ [ʃe] gesagt.
Ich hab’ [ʃo] gesagt.

Ich hab’ [xi] gesagt.
Ich hab’ [xu] gesagt.
Ich hab’ [xe] gesagt.
Ich hab’ [xo] gesagt.

Ich hab’ [si] gesagt.
Ich hab’ [su] gesagt.
Ich hab’ [se] gesagt.
Ich hab’ [so] gesagt.

Ich hab’ [iç] gesagt.
Ich hab’ [uç] gesagt.
Ich hab’ [eç] gesagt.
Ich hab’ [oç] gesagt.

Ich hab’ [iʃ] gesagt.
Ich hab’ [uʃ] gesagt.
Ich hab’ [eʃ] gesagt.
Ich hab’ [oʃ] gesagt.

Ich hab’ [ix] gesagt.
Ich hab’ [ux] gesagt.
Ich hab’ [ex] gesagt.
Ich hab’ [ox] gesagt.

Ich hab’ [is] gesagt.
Ich hab’ [us] gesagt.
Ich hab’ [es] gesagt.
Ich hab’ [os] gesagt.