Chapter 4

A PHONETIC STUDY OF GUARANÍ

In this chapter I report on an acoustic study of intervocalic voiceless stops in oral versus nasal contexts in Guaraní. Guaraní is a language well-known for its nasal harmony, in which all voiced segments become nasalized and voiceless segments behave transparent. An acoustic comparison of oral and nasal word pairs in Guaraní provides information about what effect, if any, nasal harmony has on transparent voiceless stops. In the previous chapter I proposed an analysis of transparency as an opacity effect, producing surface orality of transparent segments in nasal harmony. The findings of the study of Guaraní confirm the need for this result by showing that voiceless stops do typically surface as oral obstruent stops in nasal spreading domains.

In addition to establishing the basic transparent character of voiceless stops in Guaraní, the study makes several findings concerning context-dependent differences in voice onset time, closure voicing, and closure duration in oral versus nasal environments. Although it is apparent that voiceless stops in nasal spans should be represented as phonologically oral, the study identifies some systematic phonetic effects of nasal contexts on voiceless stops. Another discovery is that the total period of voicelessness appears to be fixed independent of context. The period of voicelessness emerges as a feature that is preserved in its total duration but is shifted in relation to stop closure and release in nasal environments. This suggests that, at least in Guaraní, the total voiceless duration is a quality contributing to the definition of voiceless stops. These results thus have implications for the phonetic correspondents of phonological features. An additional interesting set of findings concern the different patterning of the velar stop /k/ in contrast to the anterior stops, /p/ and /t/. The velar stop fails to conform to some of the generalizations established for the other places of articulation. I hypothesize that this separate behavior of /k/ is a consequence of a threshold effect in which the velar stop reaches either a sufficient or maximal limit in its voice onset time, preventing a rightward shift of the voiceless period with just these segments.

This chapter is organized as follows. In section 4.1, I give background on the pattern of nasal harmony in Guaraní. Section 4.2 outlines the set-up of the acoustic study, describing how the data was collected and the method of instrumental analysis. In section 4.3 I report on the results of the study, first highlighting the general patterns, then detailing differences in timing in oral versus nasal contexts, and finally addressing the fixed quality of the total voiceless period. Section 4.4 discusses the implications of these results and provides a schematic scenario of what changes take place in oral versus nasal contexts. Section 4.5 briefly outlines a two-burst phenomenon observed in a small set of tokens, which appears to be correlated to nasal contexts. 4.6 is an appendix presenting the word pairs used in the study.

4.1 Nasal harmony in Guaraní

Gurani belongs to the Tupí family of South America. The Tupí family is geographically located at points along the Amazon River and tributaries, in Paraguay, regions of Bolivia and Brazil, Northern areas of Peru and Argentina, and the South of French Guiana. The Guaraní language is centered in Paraguay, where it is one of the country’s two official languages (along with Spanish) and is spoken by approximately two million people. Guaraní is also spoken in bordering regions of Argentina and Brazil. A large number of Paraguayan Guaraní speakers (over 50%) also speak Spanish; use of Guaraní predominates in rural areas and in certain sociolinguistic contexts. There are several grammars and dictionaries of Guaraní (e.g. Guasch 1948, 1956; Osuna 1952; Gregores and Suárez 1967), but little instrumental phonetic study of the language has been documented.1

Nasal harmony in Guaraní has excited much discussion amongst phonologists and phoneticians alike (see Gregores and Suárez 1967; Leben 1973; Lunt 1973; Rivas 1974, 1975; Anderson 1976; Goldsmith 1976; Sportiche 1977; Vergnaud and Halle 1978; Hart 1981; van der Hulst & Smith 1982; Poser 1982; Binvin 1986; Piggott 1992; Cohn 1993a; Trigo 1993; Flemming 1993; Steriade 1993d; Fenner 1994; Ladefoged & Maddieson 1996; Piggott and Humbert 1997; Beckman 1998; among others). Various aspects of the pattern of nasal harmony are of theoretical interest. These include the transparency of voiceless segments, the nasal allophones of voiced segments, the interaction with metrical structure, effects of spreading across morphemes, and the role of prenasalized segments. The present study focuses on the first point: the transparency of voiceless segments in nasal harmony. I will outline the other main points to establish the appropriate set-up for the phonetic investigation. The following description draws on Gregores and Suárez (1967) and Rivas (1974, 1975).

The surface consonant inventory for Guaraní is given in (1) (after Rivas 1975: 134). The representation [a/b] indicates two allophones of the same phoneme.

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1 Another Tupí-Guaraní language, Guarayu, has had some acoustic investigation by Crowhurst (1998).
Guaraní surface consonant inventory:

- Labial
- Dental
- Alveolar
- Velar
- Labiovelar
- Glottal

Voiced stops: p, t, k, kW

Vocalic stops and affricates: mb, mnd, đ, Ng, NgW, Nw

Fricatives: s, Sx, h

Sonorants: v, v), l, l', r, f, f', fW, fW

A few notes on these segments are in order. First, all the voiced segments have oral and nasal allophones, the oral allophones occurring in the onset to an oral vowel and then nasal allophones occurring before nasal vowels — consonants occur only in onsets, the basic syllable structure is open, (C)V (Rivas 1975: 135).

Voiced stops are realized as prenasalized in oral syllables and as fully nasal stops in nasal syllables. The alveolar voiced obstruent has variable oral realizations, ranging among [dj], [dž], [ž], [j], with the prestopped forms occurring in stressed syllables and fully continuant variants occurring elsewhere. In nasal syllables, ... stop, which sounds like it is articulated in the prepalatal or palatal region. The segments transcribed as [v], [f], and [fW] are grouped by Rivas with the sonorants, and they are described by Gregores and Suárez as frictionless spirants (1967: 81-2). In nasal syllables, these segments are produced as nasal approximants. The segment transcribed as [r] represents a voiced alveolar flap. Voiceless segments are reported to have voiceless oral allophones in all environments. The velar fricative is in free variation with the glottal [h] (Gregores and Suárez 1967: 81).

The Guaraní vowels are listed in (2) (Rivas 1975: 134). There are three vowel heights and three degrees of tongue advancement. Nasalization is phonemic in vowels in stressed syllables; elsewhere the distinction is allophonic.

(2) Vowel inventory:

Front
- high: i, i', ˆ, ˆ', u
- mid: e, e', o, o'
- low: a

Central
- Back

Rivas notes three exceptions to the open syllable generalization. All three cases involve a coda nasal preceding a voiceless stop. Rivas points out that each of these words are interjections and can thereby be exceptional with regard to canonical structure (1975: 135).

Nasal harmony in Guaraní produces cross-segmental spans of nasalization in words. Bidirectional nasal spreading in the word is triggered by the nasal close of a previous nasal stop. In words with prefixes, nasalization in the root is blocked by the nasal close of a prefixal nasal stop. In words with suffixes, nasalization in the root spreads to the suffix (see examples above). The situation is somewhat more complicated than this.

Nasal spreading is also triggered by the nasal closure of a prenasalized stop. In this case, as would be expected, spreading is always regressive.

Nasalized vowels are included in the above inventory, but no examples from the literature have been found illustrating such cases.

The Guaraní vowels are listed in (2) (Rivas 1975: 134). There are three vowel heights and three degrees of tongue advancement. Nasalization is phonemic in stressed syllables; elsewhere the distinction is allophonic.
Alternating suffixes are unstressed in all but two cases; fixed oral suffixes are always stressed and fixed nasal suffixes may be stressed or unstressed. Fixed suffixes do not usually affect the oral/nasal status of the stem. However, if the suffix is nasalized, it will nasalize the root as well.

The pattern is illustrated below with the fixed oral suffix, [+oral] 'past'. In (a), this suffix remains oral after a nasal stem. In (b), it produces orality on the final syllable of an otherwise nasal root:

(a) /iruɔ/ + re@ /fi[r'i]ruɔre@/ (Rivas 1975)

friend + PAST 'ex-friend'

(b) /me̞e̞dɔ/ + re@ /fi[me̞e̞]dɔre@/ (Rivas 1975)

marry + PAST 'widow(er)'

cf. /me̞edɔ/ /fi[me̞]na/) (G & S 1967)

'husband'

The purpose of this summary of the data is primarily to review the facts in order to avoid any complications in the nasalization patterns in forms used in the study. The complexities of Guaraní nasalization are dealt with later.

3 The two alternating stressed affixes are the derivational suffixes: [-o@] and [-se@] (Gregores and Suárez 1967: 103). 4 Rivas also identifies a different kind of suffix behavior exhibited by a 'special class' of suffixes (1975: 138). Suffixes belonging to this class contain an oral stressed vowel and begin with either a voiceless stop or a voiced sonorant of the group [v, ŋ, ř]. After a nasal root, the suffix-initial consonant is changed to a homorganic voiced prenasalized stop and the suffix vowel remains oral. For some suffixes in this group the change is obligatory and for others it is optional.

Voiceless consonants are transparent to nasal harmony:

P1: *NASOBS >> IDENT'

' O[±voice] >> IDENT'

'O[+nasal]  

P2: SPREAD([+nasal], M) >> NASLIQUID >> *NASGLIDE >> *NASVOWEL

Because the nasal spreading constraint outranks all P2 nasalization constraints, this ranking selects a sympathetic candidate in which nasalization spreads to all segments in a nasal morpheme. The P1 nasalization constraint then rules out any candidates containing nasalized obstruents, and I

DENT-

'O[±voice] >> IDENT-

'O[+nasal] selects the candidate with nasalization of all voiced segments. This analysis yields an output with surface-oral voiceless stops.

Before proceeding to outlining the details of the set-up of the phonetic study, I will briefly review the analytical implications of some of the other aspects of Guaraní nasal harmony. First, Guaraní nasalization is sensitive to stress. The nasalization of stressed syllables can derive the effect of nasalized nasal harmony in Guaraní.

Recall that nasalization is a property of stressed syllables, with nasal features having primary stress. In stressed syllables, the nasal feature of the root is transferred to the suffix.

The nasalization of unstressed syllables is derived from the nasalization of their stressed counterparts, resulting in a general asymmetry of nasal harmony.

On the subject of syllable patterns with voiced stops, Beckman (1998) develops an insightful analysis, drawing on the aperture-theoretic representations of segments proposed by Steriade (1992). The analysis is based on the idea that nasality between adjacent positions of identical degree of aperture (e.g. stop release and a following vowel) can be modeled using a V OINAS constraint, demanding that the closure phase of a voiced stop be nasal.

Production of nasalized stops in contrastive nasal contexts is aimed in part at verifying the notion that nasalized stops in oral contexts are transparent to nasal harmony. The nasalization of oral vowels is expected to interact with nasalized stops in adjacent positions, resulting in nasalization of the vowel as well.
Beckman is able to explain the syllable nasalization patterns for voiced stops in Guaraní. For the details of this account, the reader is again referred to Beckman’s work.\(^5\)

The core analysis of nasal spreading to voiced stops in Guaraní will parallel that of the Tucanoan family. In Guaraní, voiced stops undergo nasal spreading when the following vowel is nasal or becomes nasal. For words in which nasalization has spread to voiced obstruent stops, \(O[\pm\text{voice}]\) is not violated by a nasal realization for voiced stops, so \(\text{IDENT-}O[+\text{nasal}]\) maps voiced stops to fully nasal sonorant stops. Guaraní also resembles the Tucanoan family in having a set of suffixes fixed in their nasality specification. This can be handled by placing a faith constraint for the class of fixed affixes outranking the constraint driving nasal spreading in the word.

This concludes the overview of Guaraní nasal harmony and its analytical implications. With the pattern of Guaraní nasalization in mind, I turn in the next section to outlining the set-up of the acoustic study of transparent voiceless stops.

### 4.2 Set-up

#### 4.2.1 Data and data collection

The goal of the present study is to compare the acoustic properties of intervocalic voiceless stops in oral versus nasal contexts.\(^6\) The data for this study consist of unsuffixed bisyllabic words of the form \((C)V\) or \((C)V\) a. \(^7\) These examples of Guaraní bisyllabic words are given in (7). A complete list of the word pairs used in the study is given in the appendix of this chapter (section 4.6).

(7) Examples of Guaraní bisyllabic word pairs:

<table>
<thead>
<tr>
<th>Nasal</th>
<th>Oral</th>
</tr>
</thead>
<tbody>
<tr>
<td>((C))</td>
<td>((C))</td>
</tr>
<tr>
<td>(CV)</td>
<td>(CV)</td>
</tr>
<tr>
<td>(è)</td>
<td>(è)</td>
</tr>
<tr>
<td>(ê)</td>
<td>(ê)</td>
</tr>
<tr>
<td>(a)</td>
<td>(a)</td>
</tr>
<tr>
<td>([\text{po}])pi'è)</td>
<td>([\text{djopi}])) 'to peel, strip'</td>
</tr>
<tr>
<td>([\text{ta}])tì'è)</td>
<td>(tatiè) 'to itch'</td>
</tr>
<tr>
<td>([\text{o})kè)è)</td>
<td>(okeè) 'to sleep'</td>
</tr>
<tr>
<td>([\text{a})pè)</td>
<td>(pè) 'to speak'</td>
</tr>
<tr>
<td>([\text{p])pò)</td>
<td>(pò) 'to jump'</td>
</tr>
<tr>
<td>([\text{b})jì)</td>
<td>(jì) 'to dance'</td>
</tr>
</tbody>
</table>

The language consultant for the study was a Paraguayan male, 32 years of age, who has spoken Guaraní since before the age of 10. The consultant’s proficiency in the language includes both native and acquired fluency. The consultant’s language background is described in the next section. The consultant’s proficiency in the language can be assessed further through the following procedures:

- Comparative discussion of the consultant’s knowledge of the language and its derivatives
- Questionnaire regarding the consultant’s exposure to the language
- Administration of an oral test
- Administration of a writing test
- Administration of a reading test

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- Questionnaire regarding the consultant’s exposure to the language
- Administration of an oral test
- Administration of a writing test
- Administration of a reading test
reviewed with the consultant in advance of the recording to ensure familiarity with all of the words. With this advance exposure, the written format of the list did not pose a problem, since many of the orthographic conventions of Guaraní follow Spanish ones.

The recordings were made with the speaker reading into a microphone in a sound-insulated room in the phonetics laboratory at the University of Massachusetts at Amherst.

4.2.2 Instrumental analysis

The recordings were digitized using a sampling rate of 20,000 Hz. Durations of various segmental components were measured on a Kay Elemetrics Computerized SpeechLab Model 4300 at the University of Massachusetts. In each vowel, intonational breaks were identified and were measured to determine the duration of vowels and the location of pauses. The recordings were then digitized and analyzed using Kay's Kaylab computer software. The VCV segment of the oral word 

I am grateful to John Kingston for permission to use the Phonetic Lab at the University of Massachusetts and for help with setting up the study as well as providing comments on analysis of the data. I would also like to thank the volunteer speakers who participated in this study. Thanks to Manuel Ferreira for consultation on the Guaraní language.
Because of the root-final stress in the bisyllabic words, the amplitude of the second vowel was much greater than the first, often resulting in a very weak spectrographic image for the first vowel. In these cases, the other points were marked before pre-emphasis was performed (pre-emphasis is not performed in the spectrogram in (8)).

From the four marked points on each token, various durations were measured. The following report focuses on five of these durations: (i) Closure Voicing, which measures from initiation of stop closure to onset of voicing; (ii) voicing overlap, which measures from the release of voicing to the onset of voicing; (iii) Close + Open voicing, which measures from initiation of voicing to the release of voicing; (iv) Closed Duration, which measures from stop closure to stop release; (v) voice onset time, which measures from the release of voicing to the release of voicing.

4.3 Results

The results of the study are presented at three levels of detail. First I summarize the general patterns of closure and voicing in both oral and nasal words. Then I discuss different properties of timing in oral versus nasal words, and the effects of place of articulation on any timing differences. I begin by summarizing the general patterns of closure and voicing in both oral and nasal words.

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4.3.1 General patterns

I begin by remarking on the general patterning of voiceless stops in both oral and nasal words. One focal observation is that /p, t, k/ are produced earlier in oral than nasal words, and so the nasals are accompanied by a longer burst, showing that the noise is greater. A simple spectrogram and waveform for the nasal word 'oke' 'door' is shown in (9).

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This acoustic information confirms the transparency effect that has been reported in the Guaraní grammars. The surface orality of the 'transparent' voiceless stops is consistent with the analysis of Chomsky & Halle (1968). This pattern is also observed in nasal morphemes, where the velum remains lowered throughout the full duration of the segment. An examination of some audio recordings of Desano (Tucanoan; Colombia) showed the same basic surface transparent character for voiceless stops in nasal morphemes (recordings were made by Jonathan Kaye 1965-1966). I am grateful to Jonathan Kaye for making his recordings of Desano available to me.

Another point on the subject of common acoustic patterns concerns voice timing. In both oral and nasal environments, voicing persists partway into the stop closure. The closure voicing is followed by a period of voiceless, which begins during the closure voicing. In oral and nasal environments, voiceless periods are pre-selected by the stop closure. These differences are discussed below. First, I outline the effects that were discovered in nasal contexts, and then by comparing aspects that remain fixed, I posit a defining acoustic property of voiceless stops.

4.3.2 Effect 1: Ratio of Closure Duration to Voice Onset Time

One of the major context-induced effects found in this study is that the average ratio of closure duration to voice onset time is greater than the nasal average. The difference is statistically significant ($p < 0.0001$).
Closure duration/voice onset time (CD/VOT) results across sample.

**Table 1: CD/VOT Results**

<table>
<thead>
<tr>
<th>Oral</th>
<th>Nasal</th>
<th>Variance</th>
<th>Average CD/VOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.375</td>
<td>5.597</td>
<td>9.990</td>
<td></td>
</tr>
</tbody>
</table>

The cause for the difference in the ratio of closure to voice onset time can be traced to both of the logically possible contributors: in nasal contexts voice onset times are longer and closure durations are shorter. The average voice onset times are given in (11): 26.64 msec. in oral words and 32.80 msec. in nasal words (p < 0.0001). The greater values in nasal words give a greater denominator in CD/VOT, yielding smaller ratios for nasal environments.

Average closure durations for the intervocalic voiceless stops are shown in (12).

**Table 2: Closure Durations**

<table>
<thead>
<tr>
<th>Oral</th>
<th>Nasal</th>
<th>Variance</th>
<th>Average Closure Dur. (msec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>165.37</td>
<td>158.20</td>
<td>0.38</td>
<td>165.37</td>
</tr>
</tbody>
</table>

So far we have considered results across the entire sample of data, but when the tokens are sorted by place of articulation of the medial stops, we find that there is an interaction between place of articulation and the difference in CD/VOT. The results for closure and voice onset times are given in (13) and (14). For both [t] and [k], the results are similar, with nasal contexts having a larger increase in closure than in oral contexts. The greater closure in nasal words gives a smaller numerator in CD/VOT, contributing to the smaller nasal CD/VOT values.

The velar, [k], is the odd one out, having no significant difference in CD/VOT in oral versus nasal environments.

In computations by place of articulation, data from all seven words pairs for [t] are included, giving a total of 216 tokens (3 x 72). The word pair for [t] excluded in comparisons across all places of articulation is [patê]/[kati'ê] chosen at random.
Voice onset time by place of articulation.

In addition to not having a different CD/VOT value in oral versus nasal contexts, [k] is remarkable in two other respects. One feature clearly visible on the bar graph in (13) is that the value of CD/VOT for [k] is consistently about 10 msec longer than for nasal bursts in other places of articulation. This difference will be discussed in section 4.5. The other stops. One feature clearly visible on the bar graph in (13) is that the value of CD/VOT for [k] is consistently about 10 msec longer than for nasal bursts in other places of articulation. This difference will be discussed in section 4.5.
Closure duration by place of articulation. 

When examined by place of articulation, it emerges that the difference in the closure duration of voiceless stops is greater in oral contexts than in nasal ones. The effect of this trend is illustrated in (15), where the results are shown for oral and nasal words. The averages are given in (16), with oral average closure duration (CD) exceeding nasal closure duration (CD). The oral closure duration is significantly different from the nasal closure duration (CD) at the 0.01 level. The ratio of closure duration to closure voicing duration (CD/CV) is also different between oral and nasal words, with the oral ratio being significantly different from the nasal ratio (CD/CV). The averages are shown in (17), with oral average CD/CV exceeding nasal average CD/CV by 1.67.

4.3.3 Effect 2: Ratio of closure duration to closure voicing duration

The second main effect discovered in the production of voiceless stops in oral versus nasal words is that the ratio of closure duration to closure voicing duration is greater in oral words than in nasal words. This is evidenced in (17), where oral average CD/CV exceeds nasal average CD/CV by 1.67. The effect of this trend is illustrated in (16), with oral average CD/CV exceeding nasal average CD/CV by 1.67.

To summarize, the findings reported so far indicate that the ratio of closure duration to closure voicing duration is greater in oral words than in nasal words, with oral average CD/CV exceeding nasal average CD/CV by 1.67. The ratio of closure duration to closure voicing duration is also different between oral and nasal words, with the oral ratio being significantly different from the nasal ratio (CD/CV). The averages are shown in (17), with oral average CD/CV exceeding nasal average CD/CV by 1.67.

(15) Closure duration by place of articulation

(16) Closure duration/Closure voicing duration (CD/CV): results across sample

<table>
<thead>
<tr>
<th>No. of tokens</th>
<th>Variance</th>
<th>Avg. closure duration (msec.)</th>
<th>df</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oral</td>
<td>36</td>
<td>168.86</td>
<td>1</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Nasal</td>
<td>36</td>
<td>158.64</td>
<td>1</td>
<td>0.54</td>
</tr>
</tbody>
</table>

For nasal tokens, the ratios are 1.67, 1.53, and 1.77, with differences in CD/CV being significant across oral and nasal combinations.

(17) Closure duration/Closure voicing duration (CD/CV): results by place of articulation

<table>
<thead>
<tr>
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To summarize, the findings reported so far indicate that the ratio of closure duration to closure voicing duration is greater in oral words than in nasal words, with oral average CD/CV exceeding nasal average CD/CV by 1.67. The ratio of closure duration to closure voicing duration is also different between oral and nasal words, with the oral ratio being significantly different from the nasal ratio (CD/CV). The averages are shown in (17), with oral average CD/CV exceeding nasal average CD/CV by 1.67.
The difference in the cases of words with \[p\] and \[k\] is not statistically significant.\(^{10}\)

(17) Closure duration/Closure voicing duration (CD/CV) by place of articulation.

//p//t//k//

\[\begin{array}{|c|c|c|c|c|c|}
\hline
\text{Place} & \text{Oral} & \text{Nasal} & \text{Oral} & \text{Nasal} & \text{Oral} & \text{Nasal} \\
\hline
\text{p} & \text{not significant} & \text{significant} & \text{not significant} & \text{not significant} & \text{Oral} & \text{Nasal} \\
\text{t} & \text{significant} & \text{not significant} & \text{significant} & \text{not significant} & \text{Oral} & \text{Nasal} \\
\text{k} & \text{not significant} & \text{not significant} & \text{not significant} & \text{not significant} & \text{Oral} & \text{Nasal} \\
\hline
\end{array}\]

No. of tokens 36 36 36 36 36 36

Variance 7.00 6.69 13.20 1.90 19.50 10.27

Avg. CD/CV 11.21 7.11 7.83 >5.09 8.83 7.28

\(\text{df} = 1\) \(p = 0.56\)

\(F = 0.34\) \(\text{df} = 1\) \(p < 0.0001\)

(18) Greater closure voicing for \[t\] in nasal contexts.

\[\begin{array}{|c|c|c|c|c|c|}
\hline
\text{Place} & \text{Oral} & \text{Nasal} & \text{Oral} & \text{Nasal} & \text{Oral} & \text{Nasal} \\
\hline
\text{p} & \text{not significant} & \text{significant} & \text{not significant} & \text{not significant} & \text{Oral} & \text{Nasal} \\
\text{t} & \text{significant} & \text{not significant} & \text{significant} & \text{not significant} & \text{Oral} & \text{Nasal} \\
\text{k} & \text{not significant} & \text{not significant} & \text{not significant} & \text{not significant} & \text{Oral} & \text{Nasal} \\
\hline
\end{array}\]

No. of tokens 36 36 42 42 36 36

Variance 0.24 0.092 0.12 0.35 0.097 0.090

Avg. closure voicing (msec.) 29.98 26.95 24.78 <34.07 22.42 24.54

\(\text{df} = 1\) \(p = 0.1\)

\(F = 2.66\) \(\text{df} = 1\) \(p < 0.005\)

\(F = 8.92\) \(\text{df} = 1\) \(p = 0.2\)

\(F = 1.69\) \(\text{df} = 1\) \(p = 0.2\)

A related property that holds consistently across all places of articulation is a shorter duration of the voiceless period of the closure in nasal contexts. This is illustrated in (19). Between oral vowels, the voiceless closure is around 140 msec. in duration, which is consistent with the voiceless closure duration for words with \[p\] or \[k\].

\[\begin{array}{|c|c|c|c|c|c|}
\hline
\text{Vowel} & \text{Oral} & \text{Nasal} & \text{Oral} & \text{Nasal} & \text{Oral} & \text{Nasal} \\
\hline
\text{O} & \text{significant} & \text{not significant} & \text{significant} & \text{not significant} & \text{Oral} & \text{Nasal} \\
\text{E} & \text{significant} & \text{not significant} & \text{significant} & \text{not significant} & \text{Oral} & \text{Nasal} \\
\text{A} & \text{significant} & \text{not significant} & \text{significant} & \text{not significant} & \text{Oral} & \text{Nasal} \\
\hline
\end{array}\]

Although closure durations were found to be shorter in nasal words for \[p\] and \[k\], the difference in the cases of words with \[d\] and \[t\] was not significantly different.
4.3.4 A fixed property: Total period of voicelessness

The last finding I will report on concerns a fixed property of voiceless stops in oral and nasal contexts. Across the sample of data, it was found that the total period of voicelessness is not significantly different in oral versus nasal words. The values are given in (20). Interestingly, when we compare the averages for total period of voicelessness by place of articulation, [k] is once again singled out in contrast to [p] and [t]. This is shown in (21). The total period of voicelessness for [k] exceeds that of the anterior stops in oral as well as nasal environments. [k] occurs in nasal contexts more frequently than [p] and [t], and therefore has a longer total period of voicelessness. However, this longer period of voicelessness for [k] is not significantly different from that of [p] and [t]. This is shown in (21) and (22). Interestingly, when we compare the averages for total period of voicelessness by place of articulation, [k] is once again singled out in contrast to [p] and [t]. This is shown in (21).

4.4 Discussion

I now will use the various findings together to construct an integrated picture of what is known for [k].

Interestingly, when we compare the averages for total period of voicelessness by place of articulation, [k] is once again singled out in contrast to [p] and [t]. This is shown in (21).
The above situation describes what has been observed for the anterior stops [p] and [t]. For [k], the voiceless closure decreases and VOT increases, except in the case of [k]. For [k], the voiceless closure remains relatively constant, holding at about 40 msec.

Average voiceless closure plotted against average VOT

<table>
<thead>
<tr>
<th>Voiceless closure</th>
<th>VOT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>10</td>
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<td>15</td>
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<td>20</td>
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<td>35</td>
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<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>45</td>
</tr>
</tbody>
</table>

Legend:
- [p, t, k]ō = [p, t, k] (respectively) in oral context
- [p, t, k]n = [p, t, k] (respectively) in nasal context

With these results in mind, I will turn to an interpretation of the findings. Timing in oral versus nasal environments in the VCV segment of the word is represented schematically in (23). Vertical lines on the right to extend farther into the following vowel. This produces the increased voice-onset time in nasal words.

The above situation describes what has been observed for the anterior stops [p] and [t]. [k] behaves somewhat differently, and the schematic representations corresponding to this segment are shown in (24). For [k], the voiceless closure remains relatively constant, holding at about 40 msec.

Average voiceless closure plotted against VOT

<table>
<thead>
<tr>
<th>Voiceless closure</th>
<th>VOT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
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<td>45</td>
</tr>
</tbody>
</table>

Legend:
- [p, t, k]ō = [p, t, k] (respectively) in oral context
- [p, t, k]n = [p, t, k] (respectively) in nasal context
The voiceless period will not shift to the right, because it has reached the limit of its extension into the following vowel. As a result, the voiceless period (a) between oral vowels is greater than the voiceless period (b) between nasal vowels.

<table>
<thead>
<tr>
<th>V</th>
<th>C</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Oral:  
|______________________|

(a) voiceless period  
shorter closure  
threshold-induced voicing

Nasal:  
|___________________|

(b) voiceless period < (a)

It was noted earlier that the threshold effect in the velar voice onset time could be one of sufficient length. From this perspective, the duration of post-release voicelessness would be sufficient to signal the voiceless quality of the stop, even under conditions of a shorter voice release. It also is conceivable that the threshold is a result of velar voice onset times reaching a maximal length. Under this view, the threshold effect in the velar post-release voicelessness could be a consequence of perceptual factors. If so, the voice release of nasal words would proceed faster than that of oral words. This account explains differences in timing as a result of a shift of voicelessness to the right in order to maintain a fixed voiceless period, and the exceptionality of velar stops is interpreted as the consequence of a threshold effect for voiceless stops in oral words. This account explains differences in timing as a result of changes in the length of syllables. The results of this study raise some other directions for future research. On Guaraní, it would be productive to replicate the study of timing effects in oral versus nasal words with a larger base of materials in order to verify the results obtained in this work.

A schematic representation of the threshold effect for /k/ is shown in the case of oral stops. However, since the threshold effect in the velar post-release voicelessness could be a consequence of perceptual factors, it may not be the case that the voiceless period in nasal words is shorter than in oral words. This is supported by a number of factors, including perceptual studies of voiceless period in nasal words, and so the total voiceless duration in nasal words is greater than in oral words, and so the total voiceless duration in nasal words is greater than in oral words because the voice onset times are shorter in nasal words than in oral words. This suggests that there is a difference in the way that voiceless stops are produced in oral words versus nasal words. This difference may be due to the fact that nasal words are produced with a shorter voice release, which results in a shorter voiceless period. In oral words, the voiceless period is longer, which results in a longer voice release.

The results of this study raise some other directions for future research. On Guaraní, it would be productive to replicate the study of timing effects in oral versus nasal words with a larger base of materials in order to verify the results obtained in this work. Further work is needed to determine whether this phonetic characteristic is universal or specific to Guaraní. It also is conceivable that the threshold effect is a result of perceptual factors. If so, the voice release of nasal words would proceed faster than that of oral words. This account explains differences in timing as a result of a shift of voicelessness to the right in order to maintain a fixed voiceless period, and the exceptionality of velar stops is interpreted as the consequence of a threshold effect for voiceless stops in oral words. However, since the threshold effect is a result of perceptual factors, it may not be the case that the voiceless period in nasal words is shorter than in oral words. This is supported by a number of factors, including perceptual studies of voiceless period in nasal words, and so the total voiceless duration in nasal words is greater than in oral words, and so the total voiceless duration in nasal words is greater than in oral words because the voice onset times are shorter in nasal words than in oral words. This suggests that there is a difference in the way that voiceless stops are produced in oral words versus nasal words. This difference may be due to the fact that nasal words are produced with a shorter voice release, which results in a shorter voiceless period. In oral words, the voiceless period is longer, which results in a longer voice release.
Various models of phonetic implementation have been proposed which map from an abstract phonological representation to a more concrete auditory one. These models account for the mapping of speaker intentions onto audible sounds. Some analysts have argued that the phonetic correlates of features are coordinated with other articulations in systematic ways. For example, Kingston's 'binding principle' posits a correspondence between the closure of a consonant and the opening of a vowel, ensuring that these articulations are synchronized. This principle can be illustrated by the use of nasalized vowels, which are more prominent in the presence of nasal consonants. The vocalic quality of such vowels is determined by the time of onset of vocalic closure, which is systematically tied to the closure of the nasal consonant.

In regard to voice timing, recall that the variances for VOT in nasal tokens were found to be at least twice that in oral tokens at all places of articulation. If this observation is rooted in the coordination of the glottal and oral articulations, then the release of the voiceless segment should coincide with the release of the vocalic closure. This is consistent with the observation that the voiceless quality of the consonant is readily perceptible. In the case of [k], the voice onset time is conjectured to have reached a threshold. If the threshold is listener-oriented, then the voice onset time in nasal tokens could be an effect of a greater voice onset time into the successive vowel. This would explain the increased voice onset time in nasal tokens, which is consistent with the idea that voiceless consonants in nasal contexts are more prominent.

In the case of [k], the voice onset time is conjectured to have reached a threshold. If the threshold is listener-oriented, then the voice onset time in nasal tokens could be an effect of a greater voice onset time into the successive vowel. This would explain the increased voice onset time in nasal tokens, which is consistent with the idea that voiceless consonants in nasal contexts are more prominent. The increase in the voice onset time in nasal tokens could be a consequence of a greater glottal abduction to inhibit post-nasal voicing. While this is an interesting possibility, the increased voice onset time across oral and nasal tokens suggests that there is actually a controlled shift in glottal timing taking place. This shift still obeys the constraint of producing voicelessness at the point of release, which is listener-oriented if the voice onset time in nasal tokens is understood as maximal. In the case of [t], the voice onset time is conjectured to have reached a threshold. If the threshold is listener-oriented, then the voice onset time in nasal tokens could be an effect of a greater voice onset time into the successive vowel. This would explain the increased voice onset time in nasal tokens, which is consistent with the idea that voiceless consonants in nasal contexts are more prominent.
voice onset as a consequence of aerodynamic factors, this would be a speaker-oriented effect. In either case, the fixed onset of voicing in the vowel following [k] is moderated by minimization of various and sometime conflicting realizational requirements. Here these are two apparent kinds of pattern seen in these exceptional tokens. Here there are no apparent exceptions to have two rather than one events associated with the burst. Some samples of voiceless stops in nasal contexts. In these cases, the voiceless stops appear to have two rather than one events associated with the burst. Some samples

In this last section I outline a somewhat different pattern observed in the release of a

4.5 Two-burst events

In this last section, I outline a somewhat different pattern observed in the release of a
In both of the two-burst patterns, the second of the burst events displayed the characteristics of the usual release of the stop with the first burst apparently resulting from a brief breach in the oral closure. While the alternation may be more compelling for the subjects only because it is easier to measure the pressure which is needed to close the differences in airflow into a venting nasal airway separately, and a reading is achieved by directing the air into a device to measure the nasal airflow, it is conceivable that some aspect of the timing of closure and opening may contribute to these nasal tokens. A less invasive apparatus (see E. Ohala 1971) on the nasopharynx would provide direct information about velar airflow through an oscillograph, and an instrument study of Guaraní making use of one of these devices would be a worthy project for future research.
4.6 Appendix: Word pairs

1. /rupaè/ [rupaè] 'bed' (1st poss.)
   /nupa)è/ [nupa)è] 'to hit'

2. /djopiè/ [djopiè] 'to itch, sting'
   /popi'è/ [popi'è] 'to peel, strip'

3. /kepeè/ [kepeè] 'asleep'
   /mbope)è/ [mbope)è] 'he/she broke'

4. /pepeè/ [pepeè] 'to flutter, flap wings' (lit.)
   /djepe)è/ [djepe)è] 'to break'

5. /djapiè/ [djapiè] 'to throw, shoot at'
   /djapi'è/ [djapi'è] 'to cut hair'

6. /hapˆè/ [hapˆè] 'to catch fire'
   /Sapi'è/ [Sapi'è] 'defective, amputated, cut off'

7. /kutuè/ [kutuè] 'to stick (with), prick, strike'
   /pˆtu)è/ [pˆtu)è] 'dark'

8. /itaè/ [itaè] 'stone, rock'
   /ˆta)è/ [ˆta)è] 'to swim'

9. /mbotˆè/ [mbotˆè] 'to close, shut'
   /mboti'è/ [mboti'è] 'to cause shame'

10. /potaè/ [potaè] 'to want, desire'
    /teta)è/ [teta)è] 'nation, country'

11. /tatiè/ [tatiè] 'daughter-in-law'
    /tati'è/ [tati'è] 'horn'

12. /patiè/ [patiè] 'name of a fish'
    /kati'è/ [kati'è] 'stinking'

13. /tataè/ [tataè] 'fire'
    /hata)è/ [hata)è] 'hard'

14. /Sukaè/ [Sukaè] 'to show'
    /tuka)è/ [tuka)è] 'toucan'

15. /pokoè/ [pokoè] 'to touch'
    /moko)è/ [moko)è] 'to swallow'

16. /okeè/ [okeè] 'to sleep'
    /oke)è/ [oke)è] 'door'

17. /hekoè/ [hekoè] 'custom, behavior' (3 poss.)
    /hoke)è/ [hoke)è] 'door' (3 poss.)

18. /djokaè/ [djokaè] 'to break'
    /moka)è/ [moka)è] 'to wipe up, wash'

19. /kakaè/ [kakaè] 'to defecate'
    /haka)è/ [haka)è] 'branch'

20. /nekè/ [nekè] 'to show'
    /nekê/ [nekê] 'toucan'

21. /nata/ [nata] 'hard', 'fire'

22. /nati/ [nati] 'hard', 'fire'

23. /hita/ [hita] 'to hit'

24. /juka/ [juka] 'to show'
    /jukê/ [jukê] 'toucan'

25. /ka/ [ka] 'hard'
    /kê/ [kê] 'fire'