The distribution and acoustic properties of fricatives in Light Warlpiri

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I hereby declare that, except where it is otherwise acknowledged in the text, this thesis represents my own original work.

All versions of the submitted thesis (regardless of submission type) are identical.

Approximately 10% of this thesis comes from recycled material. The material comes from an assessment entitled 'Investigating a voicing distinction in Light Warlpiri reflexes of English alveolar fricatives' and was part of course LING8027 (through the shell course LING4009: Language Methodologies Topics).

Ethics clearance for this data was obtained from the University of Michigan and the Australian National University by Dr Carmel O'Shannessy. Permissions were also obtained from the relevant individuals and organisations, and speakers were anonymised and are identified only by a code, e.g. A31. Data collection was funded by the National Science Foundation Grant #1348013.

Signed

Caroline Hendy, October 2019

Abstract

This thesis examines potential fricatives in Light Warlpiri, an Australian mixed language with Warlpiri, Kriol, and English adstrates. Most Australian languages, including Warlpiri, lack contrastive fricatives. Because of this, any inherited fricatives in Light Warlpiri – including those that have come through Kriol – are originally from English. However, the fricative inventories of Standard Australian English, Australian Aboriginal English, and Kriol differ in terms of which places of articulation are differentiated and whether voicing is contrastive. The aim of this thesis is to establish whether fricatives exist in Light Warlpiri, to investigate their acoustic properties if so, and to compare these properties with those of the Light Warlpiri source languages.

This thesis consists of two studies using elicited data from 10 first language speakers of Light Warlpiri. The first study investigates the presence and distribution of potential fricatives in Light Warlpiri. It is found that Light Warlpiri lacks /h/, and reflexes of English dental fricatives are realised as stops. The second study is an acoustic analysis of the subset of potential fricatives that are produced as fricatives. It is shown that Light Warlpiri speakers differentiate fricative production by the place of articulation of the English source. Voicing is shown to be contrastive for labiodental fricatives, but not for alveolar or postalveolar fricatives. These results show that the fricative inventory of Light Warlpiri has significant influence from Standard Australian English, but differs from all of its source languages.

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Chapter 1: Introduction

1.1 Overview

Light Warlpiri is an Australian Aboriginal mixed language with input from Kriol (an English-lexifier creole), Standard Australian and Aboriginal Englishes, and Warlpiri (Pama-Nyungan) (O'Shannessy, 2006). This thesis examines Light Warlpiri 'potential fricatives'; segments in Light Warlpiri that correspond to fricatives in English source words. Fricatives are consonants categorised by the partial obstruction of the airstream and the presence of turbulent airflow (Ladefoged & Johnson, 2011). Contrastive fricatives are uncommon in Australian languages (Fletcher & Butcher, 2014), including Warlpiri (Laughren, 1984). Because of this, any inherited fricatives in Light Warlpiri – even those that have come through Kriol – are originally from English.

Summarised in Table 1 below, Standard Australian English has eight contrastive fricatives: /f/ as in '**f**un'; /v/ as in '**v**an'; /θ/ as in '**th**ing'; /ð/ as in '**th**is'; /s/ as in '**s**un'; /z/ as in '**z**oo'; /ʃ/ as in '**sh**op'; and /ʒ/ as in '**g**enre'. English also has /h/ as in '**h**ouse', though its status as a fricative is less clear. Kriol has /h/ as in ***h**anggri* 'hungry', /f/ as in ***f**emili* 'family', /s/ as in ***s**abi* 'know, understand', and /ʃ/ as in ***sh**ip* 'sheep' (Baker, Bundgaard-Nielsen, & Graetzer, 2014). However, it lacks contrastive fricative voicing, so that there is no phonological /v, z/ or /ʒ/. The presence of fricatives in Aboriginal English varies (Butcher, 2008). By analysing the potential fricatives in Light Warlpiri, this thesis aims to provide a picture of the situation that results from this complex input.

Table 1 Phonemic fricatives in English, Kriol, and Warlpiri

	Labio-dental	**(Inter-) dental**	**Alveolar**	**Palato-alveoar**	**Glottal**
Standard Australian English	f v	θ ð	s z	ʃ ʒ	h
Kriol	f		s	ʃ	h
Acrolectal Aboriginal English			s	ʃ	
Basilectal Aboriginal English					
Warlpiri					

This thesis consists of two studies using elicited data from 10 first language (L1) speakers of Light Warlpiri. The first study investigates which potential fricatives are present in Light Warlpiri. For those present, the distribution of fricative versus stop realisation is then analysed. The second study is an acoustic analysis of the subset of potential fricatives that are realised as fricatives in the data. This provides a picture of whether place of articulation and voicing are contrastive for Light Warlpiri fricatives.

The primary research questions this thesis seeks to address are:

1. Are the reflexes of English fricatives produced as fricatives in Light Warlpiri?
2. If they are, are fricatives corresponding to different places of articulation in English distinct from one another?
3. Are English-like fricative voicing distinctions maintained in Light Warlpiri?

Answering these research questions will provide insight into how English-origin fricatives have been adapted in Light Warlpiri, and provide evidence on which to base a proposal for the fricative inventory of the language.

1.2 Fricatives

Fricatives are consonants categorised by the partial obstruction of the airstream and the presence of turbulent airflow (Ladefoged & Johnson, 2011; Ladefoged & Maddieson, 1996). The speaker produces a narrow supra-glottal constriction in the vocal tract, which causes the airflow to become turbulent. This turbulence generates noise.

Cross-linguistically, /s/ is particularly common, occurring in 67% of phonemic inventories across the 2186 languages in the PHOIBLE database as of 2019 (Moran & McCloy, 2019). The next most common fricative, /ʃ/, is found in 37% of the inventories, followed by /z/ in 30%. In general, if a language has a voiced fricative it will also have its voiceless counterpart (Maddieson, 1984). Fricatives are uncommon in traditional Australian languages, with only a handful of exceptions such as Anuthimri on the Cape York Peninsula and Ngan'gityemerri in the Daly River area (Fletcher & Butcher, 2014).

Fricatives are more difficult to produce than stops and nasals (Ladefoged & Maddieson, 1996). Precise coordination is required to create a constriction that is small enough to produce turbulence but avoids complete obstruction. For many fricatives, the shape of the articulators must be precisely maintained for the duration of the segment, or it will not be identifiable (p. 135). Fricatives also tend to be acquired by children during first language acquisition later than other consonants (Gruber, 1999; Smit, 1993).

The phoneme /h/ is sometimes classified as a fricative due to the production of airstream turbulence at the glottis (Johnson, 2012; see also tabulated versions of the International Phonetic Alphabet [International Phonetic Association, 2015]). However, others have classified it as an underspecified segment (Keating, 1988), or as indicating the weakening of the voicing of an adjacent segment (Ladefoged, 1971; Ladefoged & Maddieson, 1996). Due to its historical classification as a fricative, though, I include it in the first study of this thesis on the distribution of Light Warlpiri fricatives (Chapter 4).

1.3 Language Background

Light Warlpiri is a mixed language that emerged in the 1980s in Lajamanu, an Indigenous community in Australia's Northern Territory (O'Shannessy, 2006). The location of Lajamanu is shown in Table 1. Lajamanu has a population of approximately 600 people, at least 81% of whom identify as Australian Aboriginal people (ABS, 2017). The oldest speakers of Light Warlpiri are up to 40 years old at the time of writing in 2019. At the genesis of Light Warlpiri, adults code-switched between Warlpiri and English or Kriol during child-directed speech, using a morphosyntactic pattern that was then conventionalised and expanded by child innovators (O'Shannessy, 2012).

Figure 1 Map showing location of Lajamanu
© 2018 Google; Data SIO, NOAA, U.S. Navy, NGA, GEBCO; Image Landsat/Copernicus Data

Verbal morphology in Light Warlpiri typically comes from English/Kriol with innovations, whilst noun morphology typically comes from Warlpiri. This is shown in examples (1) and (2), where the English/Kriol-derived morphemes are in plain print, and those derived from Warlpiri are in *italics*, after O'Shannessy (2006).

(1)	de-m	jeis-ing	it	*kuuku*	det	tu	*karnta-jarra*
	3PL-NFUT	chase-PROG	3SG.O	monster	that	two	girl-DUAL

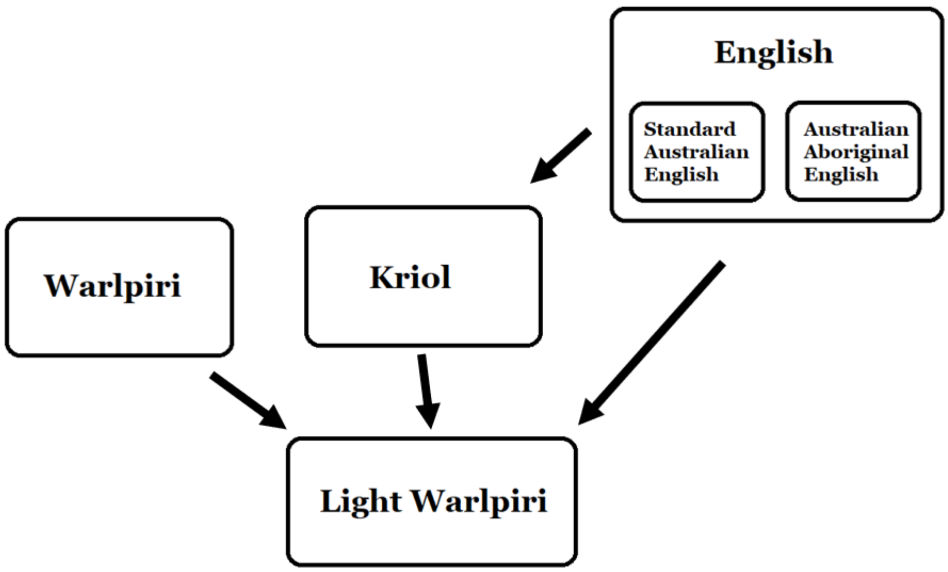
'Those two girls are chasing the monster.' (O'Shannessy, 2006, p. 9)

(2)	*rdaka-ngka*	i-m	old-im	*kuja-ng*	*jurlpu*
	hand-LOC	3SG-NFUT	hold-TR	thus-ERG	bird

'He's holding the bird in his hand like this.' (O'Shannessy, 2006, p. 9)

A range of lexicons are spoken in Lajamanu and were available for input into Light Warlpiri at its genesis. These include Warlpiri, Kriol, Aboriginal Australian English, and Standard Australian English. A visual representation of how these languages have contributed to Light Warlpiri is given in Figure 2 below. These languages will be briefly introduced later in this chapter.

Figure 2 Language relationships to Light Warlpiri



Although current research has built an ever-clearer picture of Light Warlpiri acquisition, its sociolinguistic situation, and morphosyntax (Meakins & O'Shannessy, 2005, 2010, 2012; O'Shannessy, 2005, 2006, 2008, 2009, 2011a, 2011b, 2011c, 2012, 2013, 2015a, 2015b, 2016a, 2016b, 2016c; O'Shannessy & Meakins, 2012), research into the Light Warlpiri sound system is only in its initial stages. O'Shannessy (2006) gives an impressionistic overview of the Light Warlpiri sound system, writing that the phonemic inventory of Light Warlpiri contains all the phonemes in both Warlpiri and Kriol (p. 23). Based on the inventories provided by O'Shannessy, this includes /f, v, θ, ð, ʃ, s/ and /h/.

The status of /θ/ and /ð/ as fricatives, however, has been challenged by their inclusion in the acoustic investigation of Light Warlpiri stops by Bungaard-Nielsen and O'Shannessy (2019). Bungaard-Nielsen and O'Shannessy successfully recorded VOT and constriction durations for word-initial /θ/ and /ð/, having identified their systematic production as stops. They did not find a VOT distinction between them.

Bundgaard-Nielsen, O'Shannessy and Baker (2015) conducted a perception test to determine if Light Warlpiri speakers discriminate stops and fricatives. Fifteen participants undertook XAB discrimination tasks which included testing word-initial /s-ʃ/, /b-v/, and /s-z/ discrimination pairs. The discrimination accuracy for all pairs was significantly greater than chance; however, /s-z/ discrimination was significantly less accurate than /s-ʃ/ and /b-v/ discrimination. Bundgaard-Nielsen et al. conclude that this indicates the Light Warlpiri fricative inventory contains /s, ʃ/ and /v/. They note that the difficulty with /s-z/ discrimination is consistent with phonological influence from Kriol, but that successful /v-b/ discrimination suggests additional influence from English.

1.3.1 Warlpiri

Warlpiri is an Australian Indigenous language of the Pama-Nyungan family. It has approximately 3000 speakers in total, spread across communities such as Yuendumu, Nyirrpi and Willowra, as well as Lajamanu (Bundgaard-Nielsen & Shannessy, 2019). Warlpiri as spoken today differs from 'classical Warlpiri' (Laughren, 1984; Nash, 1986) by sound changes such as final-vowel deletion and cluster modification (O'Shannessy, 2006, p. 20)[1]. Children in Lajamanu acquire both Light Warlpiri and Warlpiri before school age (O'Shannessy, 2006, p. 76).

Warlpiri lacks contrastive fricatives (Laughren, 1984). Because of this, I do not go into the contribution of Warlpiri to Light Warlpiri in this thesis.

1.3.2 Kriol

Kriol is an English-lexifier creole spoken across Australia's north. Speaker estimates vary between 15,000 and 30,000 speakers (Dickson, 2015). The variety that has received the most attention in the literature on the Kriol sound system to date is Roper Kriol (e.g. Baker et al., 2014; Bundgaard-Nielsen & Baker, 2016; Sandefur, 1979). Roper Kriol is the variety spoken in the Roper River Region, including the communities Ngukurr and Numbulwar. Sandefur and Harris estimated in 1986 that Kriol was then used in approximately 270 Aboriginal communities.

Kriol is derived from a pidgin English that originated in the Pacific and developed into New South Wales Pidgin English from the time of colonisation. This pidgin spread north to Queensland through the pastoral industry during the mid-19th Century, and a variety spoken by Aboriginal people spread across much of Australia's north (Meakins,

[1] O'Shannessy, Culhane, Kalyan and Browne (in preparation) are presently analysing changes in phonotactics across all remote Warlpiri-speaking communities.

2014, p. 370-1). Kriol's first known appearance was at the Roper River Mission, now Ngukurr, in southern Arnhem Land in the early 1900s (Harris, 1993). Kriol appears either to have spread from there, or speakers creolised the pidgin in different locations across Australia's north at the start of the 20^{th} Century (Harris & Sandefur, 1985; Meakins, 2014). After Warlpiri people were forcibly relocated by the government to Hooker Creek, now Lajamanu, in the 1940s and 1950s, many of them went to work on neighbouring cattle stations. Kriol was the *lingua franca* at such stations, where Indigenous people of many different language backgrounds were made to work in very poor conditions (O'Shannessy, 2013, p. 342).

Historically, Kriol is described as having a variable sound system that spans a continuum from Standard Australian English-like to traditional Australian language-like (e.g. Sandefur, 1979, p. 49). This variability has been reported not just between speakers but also within the speech of individual Kriol speakers (Sandefur, 1979; Sandefur & Harris, 1986). Although there is of course variation within the languages at the continuum's terminal points, there are general trends that distinguish them. Voicing is contrastive in the Standard Australian English stop and fricatives series, and the stop and fricative series also contrast. In traditional Australian languages, on the other hand, obstruent inventories tend to lack stop-fricative and voicing contrasts but have many place of articulation contrasts for stops and sonorants (Fletcher & Butcher, 2014). Language varieties closer to the Standard Australian

English end of the continuum are termed ‘acrolectal’, and those towards the traditional Australian language end are termed ‘basilectal’.

However, the application of this continuum model to the Kriol sound system has been challenged initially by Baker, Bundgaard-Nielsen, and Graetzer (2014), and then more fully by Bundgaard-Nielsen and Baker (2016). Bundgaard-Nielsen and Baker showed that Kriol speakers cannot ‘slide’ into more acrolectal phonological perception when judging English obstruent contrasts. Baker et al., using data from three Kriol speakers, found that Kriol has an invariable obstruent inventory.

However, Stewart, Meakins, Algy, Ennever, and Joshua (to appear) showed that just 10 out of 20 Kriol participants clearly distinguished stops and fricatives, a contrast included by Baker et al. (2014) in their obstruent inventory of Kriol. Stewart et al. suggest that, if Kriol speakers are producing consistent contrasts without the corresponding perceptual contrasts, production could reflect phonetic choices that enhance cognitive processes or aesthetics. Alternatively, they suggest, the difference between the perceptual and production findings indicates a change in progress, or the relative unimportance of the contrasts for comprehension in Kriol.

1.3.3 English

English in Australia is broadly classifiable into Standard Australian English, Aboriginal English, and Ethnocultural dialects (not discussed here) (Cox & Palethorpe, 2007). A detailed introduction to English in Australia can be found in Burridge and Mulder (1998).

Standard Australian English

Standard Australian English shares its consonants with the standard varieties of other 'inner circle' world Englishes such as those of the US, UK, and New Zealand (for more on Kachru's concentric circle model of world Englishes see Kachru, Kachru, & Nelson [2006]). It can be further divided into broad, general, and cultivated varieties (Mitchell & Delbridge, 1965), distinguished predominantly by phonetic differences in vowel production (Harrington, Cox, & Evans, 1997). General Standard Australian English is the most common of these, and increasingly so; only approximately 10% of Standard Australian English speakers use the cultivated varieties reminiscent of British Received Pronunciation. There is also a trend away from broad varieties, which are associated with rural areas and are somewhat stigmatised (Horvath, 2008).

The Standard Australian English of non-Warlpiri people in Lajamanu varies from broad to general. It is used in the school and in interactions with and between non-Warlpiri people. It is also heard through media such as the internet, movies, music, TV and radio; these also provide exposure to American and British Englishes (O'Shannessy, 2013).

Australian Aboriginal English

'Aboriginal English' is the term applied to varieties of English spoken by Aboriginal people in Australia. Some varieties of Aboriginal English have either historical or present influence from contact languages (Malcolm, 2000b). However, it differs from Kriol and other Australian contact languages in that it is generally mutually intelligible with other varieties of English in Australia, though with some semantic differences (Kaldor & Malcolm, 1991).

Because of high degrees of multilingualism and language transference between varieties of English and Kriol, it is often not possible in Light Warlpiri to tell whether an element has come from Kriol, Standard Australian English, or Aboriginal English. Consequently, O'Shannessy often groups these sources together as English/Kriol when writing on Light Warlpiri (e.g. O'Shannessy, 2006, 2013).

1.4 Mixed languages

Mixed languages are languages that arise in situations of widespread bilingualism, and are the fusion of (usually) two source languages which are identifiable in the resulting mix. They are a type of contact language but are distinct from pidgins and creoles, which have different social histories from mixed languages and lack the advanced-bilingualism precedent (Thomason, 1997, p. 80). As O'Shannessy (2013) describes, Light Warlpiri is what Bakker (2003, p. 122) would label a V(erb)-N(oun) language; a language that draws its verbal morpho-syntax from one source and its nominal morpho-syntax from another. The ancestral language, Warlpiri, provides the majority of the nominal grammar, and the introduced language, English/Kriol, provides the majority of the verbal grammar, with innovations (O'Shannessy, 2013).

Another Australian mixed language that has been the subject of extensive research is Gurindji Kriol, and there have been several collaborative works comparing aspects of it with Light Warlpiri (Meakins &

O'Shannessy, 2005, 2010; O'Shannessy & Meakins, 2012). Like Light Warlpiri, Gurindji Kriol has Pama-Nyungan and Kriol adstrates. It is also a V-N language with the nominal grammar deriving from the ancestral language, Gurindji, and the verbal grammar deriving from the introduced language, Kriol (McConvell & Meakins, 2005; Meakins, 2013). Both Gurindji Kriol and Light Warlpiri contribute to the retention of ancestral language and identity in their respective communities (Meakins, 2008; O'Shannessy, 2013). However, Light Warlpiri has the added social function of cultivating a Lajamanu Warlpiri community identity, as distinct from Warlpiri people in other locations, and has more direct influence from varieties of English (O'Shannessy, 2006). There have been several studies on the Gurindji Kriol sound system (Buchan, 2012; Jones & Meakins, 2013; Jones, Meakins, & Muawiyath, 2012; Stewart, Meakins, Algy, Ennever, & Joshua, to appear; Stewart, Meakins, Algy, & Joshua, 2018). Those with information relating to fricatives are discussed in section 2.3.

Whether or not mixed languages have multiple phonologies has been the subject of some debate. Papen (2003) and Van Gijn (2009, p. 104-5) argue that the phonology of Michif – another V-N mixed language, combining French and Plains Cree (Bakker, 1997) – is stratified according to source language. Prichard and Shwayder (2014), Fitzsimmons, Konnelly, Provan, and Root (2015), and Rosen, Stewart, and Sammons (2016) contest this, arguing that the situation is more complex than would allow a clear source-language divide. Rosen, Stewart, Pesch-Johnson and Sammons (2019) have suggested that the ancestral languages play a larger role in the phonology of a mixed language than the introduced language, citing their findings for VOTs in Michif, as well as analyses of Gurindji Kriol (Stewart, Meakins, Algy & Joshua, 2018) and Media Lengua (a mix of Spanish and Quechua) (Stewart, 2018).

An example of the complex ways in which competing phonologies are reconciled in a mixed language can be seen in Light Warlpiri itself. In a study of Light Warlpiri stops, Bundgaard-Nielsen and O'Shannessy (2019) found word-initial voice onset timing (VOT) distinctions in bilabial and alveolar stops, with only some speakers producing VOT distinctions in velar stops. They concluded that speakers of Light Warlpiri appear to have 'amalgamated' the phonemic inventories of Warlpiri and English/Kriol, incorporating all places of articulation from Warlpiri, VOT distinctions from English/Kriol, and constriction duration contrasts that likely come from Kriol (p. 4).

1.5 Significance of the thesis

The findings from this thesis provide insight into how input from competing phonologies is dealt with in the acoustics of a mixed language. They will also provide evidence that can be used to improve phoneme inventories of Light Warlpiri. Apart from the intrinsic scientific merit, this could be useful if the speakers want to design a practical orthography.

The work will also give a point of comparison with other languages, as well as for any future research on the L1 acquisition of fricatives by Light Warlpiri speaking children. Finally, since children in Lajamanu are required to learn in Standard Australian English at school, it will provide information that can be used by teachers in Lajamanu to better tailor their English language teaching to their students' needs.

1.6 Terminology and notation

I follow the lead of Buchan (2012) in referring to the Light Warlpiri segments under investigation in this thesis as 'potential fricatives'. A 'potential fricative' refers to a segment in Light Warlpiri that may or may not be a fricative, but which corresponds to a phonemically fricative segment in English.

Whether a Light Warlpiri segment is a potential fricative is determined by its placement in the Light Warlpiri word and how this corresponds to the position in the English source word, remaining sensitive to other morphological or sound changes that may have affected the word. For example, in the Light Warlpiri word *uuju*, 'horse', the orthographic *j* is a potential fricative corresponding to word-final English /s/, even though it is not word-final in Light Warlpiri. Similarly, in the Kriol word *brogbrog* 'frog', both the first and second *b* are potential fricatives corresponding to a single English /f/, since the Kriol word has reduplication. Generally, though, the position of Light Warlpiri potential fricative corresponds directly to the position of its English fricative source.

Another key term, 'reflex', will be used in this thesis. 'Reflex' is used in historical linguistics, and it refers to a form that was derived from an earlier form. For example, as will be discussed in section 2.2, the Kriol reflex of English /z/ is /s/. This means that English /z/ became Kriol /s/.

When slanted brackets // have been used in this thesis, they refer to the phonemic English fricative cognate of the Light Warlpiri potential fricative under discussion, as a convenient way of classifying the potential fricatives. Unless otherwise specified, the use of slanted brackets is not intended to make a claim about the phonemic status of the segment in Light Warlpiri.

1.7 Thesis structure

The next chapter (Chapter 2) discusses the current state of knowledge on fricatives in the languages introduced in this chapter. The chapter concludes with a discussion of what might be expected from Light Warlpiri fricatives based on this literature.

Chapter 3 presents the literature on the methods used in the acoustic analysis study in Chapter 5. It also presents the details on data collection, participants, and materials used, which are common to both studies presented in this thesis.

Chapter 4 presents a study on the presence and distribution of fricatives in Light Warlpiri, including an analysis of stop-fricative variation. Based on these findings, the fricative status of potential Light Warlpiri fricatives is discussed.

The second study is presented in Chapter 5. This is an acoustic analysis of those potential fricatives in Light Warlpiri with fricative realisations. The evidence for place of articulation and voicing contrasts in the Light Warlpiri fricative series is then discussed.

Chapter 6 presents a general discussion connecting the two studies and comparing the results with other languages. A fricative inventory of Light Warlpiri is proposed, and the implications for mixed language research are discussed. The chapter ends with a discussion of the study limitations and some suggestions for future research. The thesis concludes briefly in Chapter 7.

Chapter 2: Fricatives in the literature

This chapter introduces the literature on fricatives in two of Light Warlpiri's source languages, English and Kriol, and another Australian mixed language, Gurindji Kriol, which has typological similarities to Light Warlpiri. Section 2.1 introduces the literature on the acoustic properties of English fricatives, followed by the literature specific to Standard Australian English (§2.1.1), and Aboriginal English (§2.1.2). Fricatives in Kriol are discussed in section 2.2, followed by a discussion of fricatives in Gurindji Kriol in section 2.3. Section 2.4 concludes with a summary of what might be expected for fricatives in Light Warlpiri.

2.1 English

English fricatives can be classed in several ways: voiced (/v, ð, z, ʒ/) versus voiceless (/f, θ, s, ʃ/); sibilants (/s, z, ʃ, ʒ/) versus non-sibilants (/f, z, θ, ð/); and by place of articulation – labiodental /f, v/, (inter-)dental /θ, ð/, alveolar /s, z/, and postalveolar /ʃ, ʒ/. Compared with non-sibilants, sibilants have a large amount of acoustic energy concentrated at high frequencies (Ladefoged, 1971, p. 57). Ladefoged (1971) writes that a sound's classification as a sibilant is language-specific; a sound considered to be sibilant in a given language may be considered non-sibilant in contrast to a more clearly sibilant sound in a different language (p. 57).

There has been a lot of work done on the acoustic properties of English fricatives since the 1950s, such as Hughes and Halle (1956), Strevens

(1960), Behrens and Blumstein (2005, 1988), Shadle (1986), Forrest, Weismer, Milenkovic and Dougall (1988), Nittrouer, Studdert-Kenneddy and McGowan (1989), Stevens, Blumstein, Glicksman, Burton, and Kurowski (1992), Nittrouer (1995), Shadle and Mair, (1996), Tabain (1998), Onaka and Watson (2000), Jongman, Wayland, and Wong (2000), Fox and Nissen (2005), Heinz and Stevens (2005), Nissen and Fox (2005), Silbert and de Jong (2008), and Maniwa, Jongman, and Wade (2009). The majority of these look at L1 speakers of American English; only Tabain's study uses Australian English-speaking adults. Several patterns have emerged from the literature with respect to the variables under examination in this thesis, and these are summarised below.

Duration

Phonologically voiceless fricatives in English are longer in duration than phonologically voiced fricatives (Baum & Blumstein, 1987; Crystal & House, 1988; Silbert & de Jong, 2008). Jongman et al. (2000) report the same effect for normalised duration – the length of the fricative divided by the length of the word containing it. Non-sibilants are generally shorter than sibilants (Behrens & Blumstein, 1988; Jongman et al., 2000), although Nissen and Fox (2005) report /f/ to be shorter than all three of /θ, s/ and /ʃ/.

Spectral moments

The literature on spectral moments will be introduced in the next chapter (§3.1). The spectral moments under analysis are the mean frequency, the variance/standard deviation, the skewness, and the kurtosis.

The mean frequency values of /s/ are consistently higher than those of /ʃ/ (Jongman et al., 2000; Nissen & Fox, 2005; Nittrouer, 1995; Nittrouer et al., 1989; Onaka & Watson, 2000). As for the variance/standard deviation, although Forrest et al. (1988) reported that it did not contribute to the classification of obstruents, Nissen and Fox (2005) and Jongman et al. (2000) both reported significantly higher variance for non-sibilants than for sibilants, and this trend is also shown by Onaka and Watson (2000). Jongman et al. found that postalveolar fricatives have the highest skewness. Similarly, Nittrouer (1995) and Nissen and Fox found that /ʃ/ had the highest skewness, and Onaka and Watson found that /ʒ/ had the highest.

Amplitude/intensity[2]

Voiceless fricatives have greater amplitude than their voiced counterparts (Jongman et al., 2000; Silbert & de Jong, 2008). Both Nissen and Fox (2005) and Jongman et al. (2000) report less normalised amplitude – the amplitude of the following vowel subtracted from the amplitude of the fricative – for non-sibilants compared with sibilants. Indeed, Jongman et al. reported that normalised amplitude significantly

[2] The intensity of a soundwave is directly proportional to its amplitude squared.

distinguished all four places of articulation, with normalised amplitude increasing the further back in the oral cavity the place of articulation – a pattern also reported by Nissen and Fox. Similarly, Silbert and de Jong (2008) reported higher noise power for alveolar fricatives compared with labiodental fricatives, and Behrens and Blumstein (1988) report lower amplitude for /f/ and /θ/ compared with /s/ and /ʃ/.

It is important to keep in mind that measures that distinguish contrastive features in English do not necessarily show the same trends as other languages. For example, whilst Nirgianaki (2014) found that Greek voiced fricatives are, like in English, shorter in duration than voiceless fricatives, the normalised amplitude of voiced fricatives were actually greater than the voiceless fricatives – the opposite trend to English.

2.1.1 Standard Australian English

Little work has been done specifically on Standard Australian English fricatives, likely due to their presumed similarity to those of the well-studied Standard American English. The Tabain (1998) study mentioned in the previous section is and a 2012 study by Buchan as part of a doctoral thesis on Gurindji Kriol fricatives are exceptions in this respect.

Tabain (1998) investigated the usefulness of spectral data above 10 kHz in the discrimination of [f] and [θ]. Although determining that the use of this data may assist in controlled recording contexts, Tabain showed that it did not improve discrimination in real-world data, and could not be used independently to classify [f] and [θ].

Buchan (2012) conducted a study on /h/-deletion and word-final /v/-deletion in the child-directed speech of mothers in Katherine. 'Katherine English', as Buchan terms it, is considered by speakers to be a 'casual or relaxed variety of Australian English with a relatively high use of vernacular,' and sits towards the broad end of the broad-cultivated Standard Australian English spectrum (p. 136). The study found that rates of /h/-deletion in Katherine English ranged from 14.00% to 39.23% across mothers, with total percentage deletion across all child ages and mothers at 28.28%. Rates of final /v/ deletion ranged from 10.31% to 23.70%, with total deletion at 18.18%.

2.1.2 Aboriginal English

Records by colonists from the first 50 years after colonisation show that English fricatives underwent considerable sound change in the development of Aboriginal English (Malcolm, 2000a). Fricatives were replaced by stops from the same or similar place of articulation wherever possible, /h/ was deleted or replaced by /k/, and there was no consistent voicing distinction (Malcolm, 2000a, p. 127). Comparing these changes with a 1990s study of the speech of Aboriginal English speakers in Sydney, Malcolm showed that /θ/ and /ð/ were still sometimes produced as stops and /h/ was still sometimes omitted. On the other hand, no evidence was found that /f, v, s, z, ʃ/ and /ʒ/ were still being replaced by stops. Malcolm also reported that 'there is no longer evidence of non-recognition of the voiced/voiceless distinction in consonants' (p. 136).

Kaldor and Malcolm (1991, p. 76) summarised other phonological features of fricatives as reported in the literature for Aboriginal English across Australia. The interdental fricatives were found to alternate with the labiodental fricatives of the same voicing quality; e.g. [wɪv] in variation with [wɪð] for 'with' and [fɪŋz] in variation with [θɪŋz] for 'things'. Affricates and fricatives were found to alternative with palatals such as [j], and fricatives were found to alternate with stops. There was also alternation between the sibilants – for example, 'boys' pronounced as [bɔɪs] and 'fish' pronounced [fɪs]. Kaldor and Malcolm also report the insertion of [h] before word-initial vowels, giving the example of 'uncle' pronounced as *huncle*, as well as word-initial [h]-deletion, such as 'hospital' pronounced *ospital*.

Butcher (2008), in a paper summarising linguistic aspects of Australian Aboriginal English, also reports this combination of h-insertion and h-deletion. Butcher reports that, at its most Standard Australian English-like, Aboriginal English speakers use both /s/ and /ʃ/. However, their use is often interchangeable, with an apparent preference for /s/ - a similar feature to the alternation of sibilants reported by Kaldor and Malcolm (1991, p. 76). Butcher's summary suggests that even the most acrolectal varieties of Aboriginal English lack a voicing distinction in fricatives. In basilectal varieties, Butcher reports that labiodental and dental fricatives are usually replaced by stops with the corresponding places of articulation. Sibilants /s, z, ʃ/ and /ʒ/, on the other hand, are realised as a sound that is typically labelled /s/ but is generally phonetically realised as ‘a voiceless laminal postalveolar lightly affricated stop’ (p. 629).

2.2 Kriol

Sandefur (1979) writes that when Kriol and its preceding pidgin were acquired by L1 speakers of traditional Australian languages, these speakers adapted English fricatives according to their L1 language phonologies. Labiodental fricatives became bilabial stops; for example, ‘family’ became /bemli/ (Sandefur, 1979, p. 37). All other fricatives became palatal stops, except /h/, which was deleted. Through sustained contact with English over time, levelling processes meant that some of these bilabial and palatal stops became fricatives once again, and /h/ was reintroduced (Sandefur, 1979; Sharpe & Sandefur, 1976).

Baker et al. (2014) discuss Kriol fricatives in their development of an obstruent inventory for Kriol. They find that the Kriol reflex of English /v/ in Kriol is /b/, and the reflex of /f/ is /f/. The English dental fricatives /θ/ and /ð/ are realised as dental stops. For other places of articulation, Baker et al. used data on fricative durations to argue that the reflex of both the voiced and voiceless English phonemes are voiceless phonemes in Kriol. English-sourced /ʃ/ and /ʒ/ become /ʃ/, whilst /s/ and /z/ become /s/. This was supported by Bundgaard-Nielsen and Baker (2016), who found that perceptual discrimination by Kriol speakers for English /s-z/ did not differ from chance.

Baker et al. (2014) also report impressionistic differences in quality between Kriol and English fricatives. Kriol /f/, they report, “has less audible frication, and more involvement of the upper lip" (p. 337), and put forward /ɸ/ as a potential candidate for future researchers to consider. Additionally, they report that many speakers' postalveolar fricatives lack the characteristic lip-rounding found in English.

Stewart, Meakins, Algy, Ennever and Joshua (to appear) conducted a study investigating the perception of stop-fricative contrasts by speakers of Kriol and Gurindji Kriol. Whilst they found that approximately half of the speakers for each language distinguished [f-pʰ] and [s-tʰ] pairs consistently, nearly half either identified all stimuli as fricatives, or clearly identified only the fricatives in each pair. The researchers conclude that such variable identification is not indicative of clear phonemic fricative-stop contrasts in the phonologies of the two languages.

2.3 Gurindji Kriol

In proposing a consonant inventory for Gurindji Kriol, Meakins (2013) writes that Gurindji Kriol speakers use /f, s/ and /ʃ/ in variation with the stop series in words derived from Kriol (p. 132). The consonant inventory given by Meakins does not include /h/. The findings from Stewart, Meakins, Algy, Ennever and Joshua (to appear) were the same for Gurindji Kriol as they were for Kriol as discussed in section 2.2 above; only just over half of participants clearly discriminated fricatives and stops.

Buchan's (2012) thesis on the production of fricatives by Gurindji Kriol-speaking mothers gives further insight into the distribution of fricatives in the language. Buchan found that in words where the potential fricative had both stop and fricative realisations, that fricative was most often a potential labiodental fricative (p. 98). In words where the potential fricative was only produced as a stop, that stop was most commonly a potential dental fricative (p. 98). Cognates of /z/ had the highest proportion of fricative realisation, with 100% of word-initial and word-medial realised as fricatives, and over 80% of word-final /z/ tokens realised as fricatives (p. 107). Fricatives were more likely to occur word-initially than word-medially or word-finally, and /s, z, ʃ/ and /f/ cognates were more likely to be produced as fricatives than cognates of other English fricatives (p. 102) Just 0.02% of potential [h] tokens were determined by transcribers to actually be pronounced with an [h] (p. 92).

Interestingly, though, a perceptual study also reported in Buchan (2012), showed that transcribers [3] perceived initial /h/ differently from L1 Gurindji Kriol speakers. Given a sample of Gurindji Kriol words, transcribers judged that only half of tokens with potential word-initial /h/ were realised with [h]. By contrast, L1 Gurindji Kriol speakers judged all of these words as beginning with [h]. Buchan suggests that this difference may be accounted for either by hypercorrection towards English, or by the presence of a sub-phonemically contrastive [h] (p. 202).

[3] It is not clear whether these transcribers are the same as those in the Buchan (2012) production study cited above.

2.4 What might we expect from Light Warlpiri?

Based on this literature, we might expect that the phonology of Light Warlpiri is not entirely like English, and not entirely like Warlpiri. There are likely to be voiceless fricatives: minimally /s/ and /ʃ/, given that these are in Standard Australian English, Kriol, and acrolectal Aboriginal English, and they were well discriminated in the Light Warlpiri perception study. Based on the same study, we can also expect /v/ to be a fricative, rather than an allophone of /b/. However, Light Warlpiri might – like Kriol and Aboriginal English – lack a fricative voicing distinction, so it is possible that /v/ is an allophone of /f/ instead. Glottal /h/ may or may not be present, given that it is found in both Standard Australian English and Kriol, but is lacking in Aboriginal English and Warlpiri. There are unlikely to be dental fricatives, given that these do not occur in any source language besides Standard Australian English, and they have already been identified word-initial as stops by Bundgaard-Nielsen and O'Shannessy (2019).

The following two chapters will show that Light Warlpiri broadly meets these expectations. It lacks /h/ and does not have a voicing distinction between /s-z/ and /ʃ-ʒ/. The sibilants /s/ and /ʃ/ are distinct, as per the perception study, and potential dental fricatives are realised as stops word-initially. Somewhat contrary to these predictions, potential voiceless dental fricatives seem to have a fricative allophone for some speakers word-finally, and there is a voicing distinction between /f/ and /v/.

Chapter 3: Methodology

This chapter presents the background literature on the methodologies used in the acoustic study (Chapter 5), followed by the data collection details that were common to both studies. The literature on spectral moment analysis is introduced in Section 3.1, followed by an introduction to the literature on voicing analysis in section 3.2. The details of the participants (§3.3), data collection (§3.4) and materials (§3.5) are then given.

3.1 Spectral moment analysis

The second study (Chapter 5) in this thesis involves a spectral moment analysis, which requires some introduction. Spectral moment analysis has frequently been used for the acoustic analysis of fricatives (e.g. Aoyama, Flege, Akahane-Yamada, & Yamada, 2019; Forrest et al. 1988; Jongman et al. 2000; Li, Edwards, & Beckman, 2009; Maniwa et al., 2009; Shadle & Mair, 1996; Silbert & de Jong, 2008; Themistocleous, 2017; Tjaden & Turner, 1997). Spectral moment analysis uses 'discrete Fourier transforms' (DFTs), which display acoustic information along frequency-power axes, rather than time-frequency axes. The DFT is treated as a probability distribution, allowing the spectral moments to be analysed (Li et al., 2009). In other words, researchers can use DFTs to measure the peaks and shape of the energy distribution, allowing for parameters like mean frequency to be obtained. The first and second moments are the mean (also called the 'centre of gravity' or 'centroid') and dispersion (variance or standard deviation) of the energy distribution, respectively. The third moment is the skewness, which indicates the distribution's symmetry. For example, alveolar fricatives, which have energy concentrated in the higher frequencies, are expected to have a negative value for skewness, reflecting their longer left tails (this is also called a 'positive tilt'). The fourth spectral moment is kurtosis. Kurtosis has variously been referred to as the 'peakedness' of a distribution (e.g. Jongman et al., 2000; Koenig, Shadle, Preston, & Mooshammer, 2013). Negative values were thought to indicate flatter distributions, with positive values indicating a more clearly defined peak. It has been shown definitively by Westfall (2014), however, that the kurtosis value has nothing to do with the peak(s) of the data. Instead, it is a measure of the tails – the higher the kurtosis, the heavier the tails. If the tails of the data are 'heavy' or 'long' then this indicates the presence of one or more outliers.

3.2 Voicing analysis

Another dependent variable under investigation in the acoustic study is fricative voicing. In articulatory terms, this refers to whether or not the vocal folds are vibrating during the fricative constriction. It is not a binary present-absent measure, however; voiceless fricatives may have a short period of voicing at the boundaries, and voiced fricatives are not necessarily voiced throughout (Stevens et al., 1992).

The first measure under investigation looked at what proportion of a fricative token had voicing. This was measured by the proportion of the sound for which pitch is detectable by Praat (Boersma & Weenink, 2019).

Praat measures pitch by automatically detecting acoustic periodicity. Since sound wave periodicity is produced by the regular closure of the vocal folds which makes a sound 'voiced', pitch detection by Praat should indicate the presence of voicing. The proportion of voicing for each fricative is obtained by dividing the duration of detectable pitch by the total duration of the fricative. Since voiced fricatives have been found to be shorter in duration than voiceless fricatives for English (Jongman et al., 2000; Stevens et al., 1992), voiced fricatives should show greater voicing proportions.

The second voicing measure is a binary variable with two levels, 'voiced' and 'voiceless'. It follows the work of Stevens et al. (1992) and Pirello, Blumstein & Kurowski (2002). By this measure, a fricative is voiced if it has greater than 30ms of glottal excitation preceding or following a vowel. If both edges of the fricative had equal to, or less, glottal excitation than this threshold, the fricative is voiceless. Stevens et al. (1992), who used 30ms after fricative onset and 20ms before following vowel onset as their thresholds, reported a greater than 83% accuracy in classifying non-word-final English fricatives as phonologically voiced or voiceless. Pirello et al. (2002), who used 30ms cut-offs for both edges, found that for syllable-initial fricatives, this measure correctly classified 99.9% of voiceless fricatives and 86% of voiced fricatives, for an overall accuracy of 93%.

The third voicing measure is also a binary variable with levels 'voiced' and 'voiceless'. It is also based on Stevens et al.'s 1992 work. They found that

English speakers would perceive fricatives as voiceless if the total time a fricative was voiceless exceeded 60ms, regardless of the length of the fricative.

3.3 Participants

The data for this thesis comes from ten L1 speakers of Light Warlpiri. All speakers are female[4]. There have all spoken both Light Warlpiri and Warlpiri from birth, but Light Warlpiri is their primary everyday language. The youngest participant is 16, the eldest in her 30s. Two participants (AC41 and LAC09) are second-generation Light Warlpiri speakers, and the rest are first-generation speakers. Participants live in Lajamanu and have not lived away from the community for more than two years. Most participants have completed Year 10, and none have completed Year 12. Participants were recruited through their connections with the recording researcher.[5]

The number of participants is commensurate with Bundgaard-Nielsen and O'Shannessy's work on Light Warlpiri stops (2019) (n = 10), and exceeds the numbers used by Baker et al. (2014) (n = 3), and Jones and Meakins (2013) (n = 5).

[4] This is due to cultural restrictions on men and women working together; the recording researcher is female.
[5] Ethics clearance for this data was obtained from the University of Michigan and the Australian National University. Permissions were also obtained from the relevant individuals and organisations, and speakers are identified by a code, e.g. A31. Data collection was funded by the National Science Foundation Grant #1348013.

3.4 Data collection

Data was collected by Dr Carmel O'Shannessy, a researcher with long-standing ties to the Lajamanu community, and who has some facility in both Warlpiri and Light Warlpiri. The researcher spoke Light Warlpiri as much as possible during recording sessions. Sessions were conducted in a quiet room of the community's Learning Centre[6], using a Marantz PMD661 recorder and either a stand-mounted Rode NT4 or a head-mounted Shure SM10A microphone. Recordings had a 16-bit sampling depth with a sampling rate of 44.1 kHz.

3.5 Materials

During the recordings, participants were presented with 82 6x4 inch photos and asked to name the object or situation depicted. Seven participants were asked to use the carrier phrase *Nyampu* ____ *amlukingit* 'This ____ I see it' five times before moving on. Three participants used the carrier phrase *Nyampu* ___ *al pudum kuja* 'This ____ I'll put it like this', and produced only one utterance per item. These carrier phrases were chosen so that the target was framed by a vowel on either side, and Light Warlpiri was clearly established as the language of the task. As Light Warlpiri is not a written language, participants were presented with images to name rather than with words to read. This meant that the choice of utterance was somewhat open. For example, some participants named the image on the right in Figure 3 below as 'lips',

[6] Under the auspices of the Batchelor Institute of Indigenous Tertiary Education (BIITE) and the Warlpiri Education Training Trust (WETT).

whilst others labelled it ‘teeth’. The photos were of images associated with Light Warlpiri words specifically chosen in an attempt to represent a variety of consonantal segments and segment positions. These words were also selected such that a variety of English, Kriol, and Warlpiri sources were represented. The order of the photos was randomised between each speaker.

Figure 3 Sample of images presented as stimuli. Intended to elicit 'lips', 'shangayi', and 'teeth'.

Chapter 4: Fricative Distribution Study

The purpose of the first study was to establish whether potential fricatives in Light Warlpiri are realised as fricatives in production. The most likely potential fricative realisations, based on the phonologies of related languages, are fricatives, stops, or zero-realisations. Fricative realisations are typically considered more Standard Australian English-like, whereas stop- and zero-realisations are considered to be more like traditional Australian language phonologies (e.g. Sandefur, 1979; Stewart, Meakins, Algy, & Joshua, 2018).

4.1.1 Coding

The data was analysed using Praat (Boersma & Weenink, 2019). Potential fricatives were coded either for their presence (in the case of /h/), or both their presence and whether they were considered a stop or a fricative (all other potential fricatives).

The manner of articulation of a potential fricative was determined by visual analysis of the Praat spectrogram. Stops were identified by a period of low intensity without high-frequency noise and the presence of a vertical bar indicating the stop release. Fricatives were identified by periods of sustained high-frequency energy. Examples are given in Figure 4 and Figure 5 below.

Figure 4 Example of the spectrogram for a potential fricative produced as a fricative

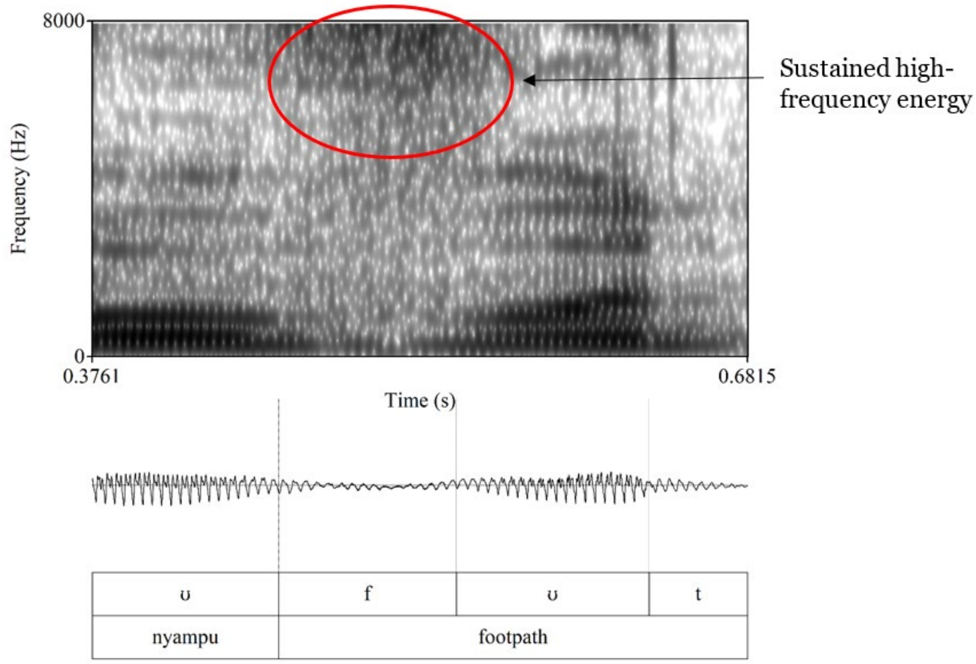
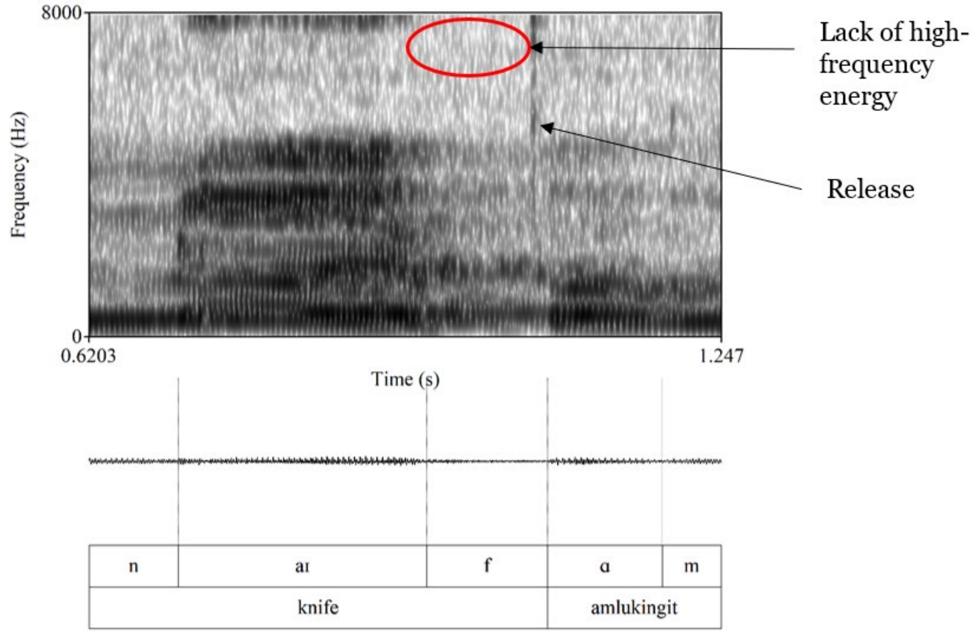


Figure 5 Example of the spectrogram for a potential fricative produced as a stop



An experienced phonetician was asked to provide manner of articulation judgements for approximately 5% (80 tokens) of the data. The sample was taken from five of the ten speakers and was made up of all tokens of the first three potential fricatives after the five-minute mark in each recording. There was 100% agreement between what the author of this thesis and the experienced phonetician judged to be stops. However, the phonetician, who provided more detailed manner of articulation judgements than the author, also judged that approximately 25% of the tokens the author had categorised as 'fricatives' to be either approximants or affricates. It was decided, due to the limitations on the scope available to this thesis, that the following analysis should include only a stop-fricative dichotomy. The approximant and affricate tokens were retained in the analysis under the 'fricative' label, with the assumption that any systematic productions of a potential fricative as one or the other would become clear in the acoustic study. It should thus be noted that the term 'fricative' as used here is more accurately 'non-stop'. The word-position of the potential fricative was also recorded, based on the position of the fricative in the English source-word (§1.6).

Apart from /h/, the potential fricative was rarely lacking. All productions of 'clothes' were produced [kləʊz] with a segment lacking in place of the potential dental frictive /ð/. Additionally, one participant produced 'scissors' as [sɪz:] in one repetition. These were excluded from further distribution analysis with respect to the missing segment. Sometimes plosives were realised as fricatives; several speakers produce the /p/ in ‘swimming pool’ as a fricative. One speaker also produced the /b/ in ‘brush’ as a fricative. Such fricatives were not included in the study as they do not meet the criteria for ‘potential fricative’. One participant pronounced ‘thong’ as [st]ong, which was coded as a stop.

A comparison of content vs function words was considered. However, it did not produce any useful information, as there were not enough tokens of function words to draw a meaningful comparison. There were only four function words with potential fricatives, compared with 139 content words. This is primarily due to the methodological design.

4.1.2 Analysis

Analyses for this study were concerned only with total token counts and proportions of tokens. A combination of Microsoft Excel (Microsoft Office 365 Professional Plus 2019, Version 1909) and the *dplyr* (Wickham, François, Henry, Müller, & RStudio, 2019) and *tidyr* (Wickham, Henry, & RStudio, 2019) packages in RStudio (R Core Team, 2019) were used to obtain this information. Graphs were created using the *ggplot* function in the *ggplot2* R package (Wickham, Chang et al., 2019).

The first part of the study looked at the distribution of fricatives and stops by word (§4.2.2). A list of the words in the dataset are provided in Appendix A. Words that were uttered only once were excluded, since they cannot be used to determine within-word variability. However, words that were uttered by only one speaker were retained. Words were coded for having their potential fricatives produced entirely as fricatives, entirely as stops, or variably, i.e. sometimes as stops, sometimes as fricatives. Those in the variable category were further examined for the number of speakers who produced them entirely as stops, entirely as fricatives, or variably.

The second part of the study looked at variability by speaker (§4.2.3). In this part, words that were uttered only once were included.

4.2 Results

Total token counts for the potential fricatives under analysis are given in Table 2 below. The second column shows the total number of words containing each fricative, excluding words that were only uttered once by one speaker.

Table 2 Token and word counts for potential fricatives

Potential fricative	Total words with multiple repetitions	Total tokens
/f/	25	340
/v/	8	140
/θ/	7	113
/ð/	3	28
/s/	39	445
/z/	12	206
/ʃ/	10	243
/ʒ/	1	25
/h/	4	67

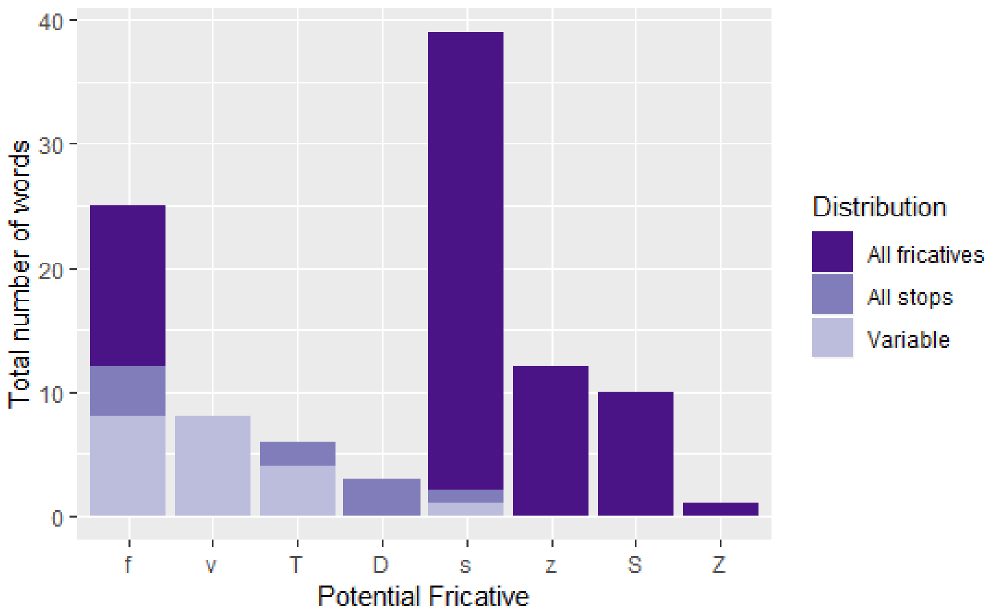
4.2.1 Potential /h/

Across 67 repetitions of words with /h/ in their English source, [h] was produced only four times, once each by two different speakers and twice by another in two different words. Thus, it was produced in just 6% of possible tokens. Potential /h/ was excluded from further analysis.

4.2.2 Variability by word

The potential fricative represented by the largest number of words was /s/, found in 39 different words, followed by /f/ (n = 25) and /z/ (n = 12). There were very few words containing /ð/ that had multiple repetitions (three: 'this', 'they're' and 'the'), and only one word contained /ʒ/ ('Casuarina Square'). This is shown in Figure 6 below. To remind the reader, the word counts in this section exclude words with only one token.

Figure 6 Manner of articulation distribution by word for each potential fricative

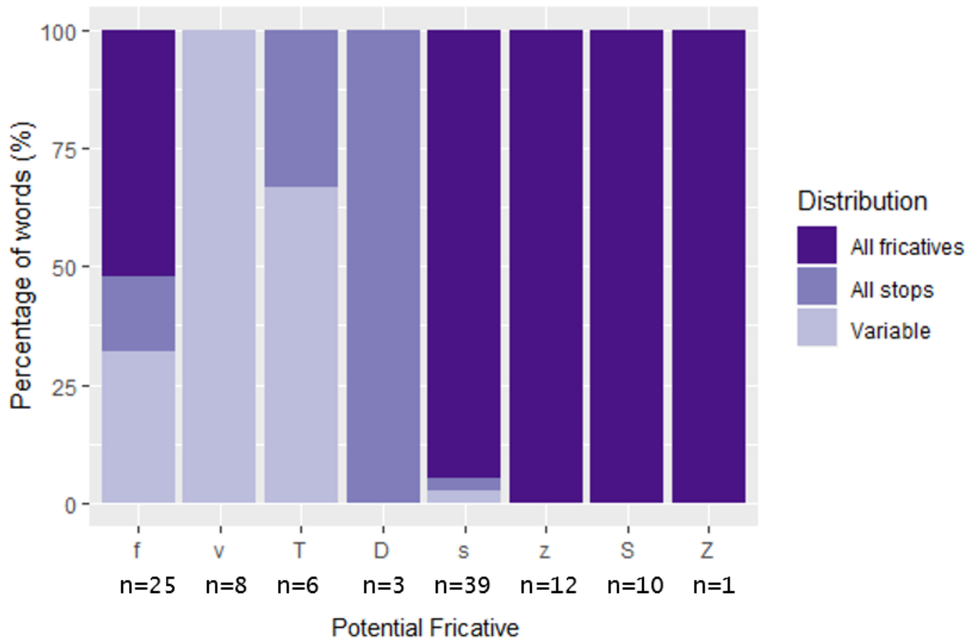


Note: T = /θ/, D = /ð/, S = /ʃ/, Z = /ʒ/

Figure 7 shows the proportions of the words containing each potential fricative that were articulated a) entirely with fricatives ('All fricatives'),

b) entirely with stops ('All stops') or c) with a combination of fricatives and stops ('Variable').

Figure 7 Manner of articulation distribution as a percentage of words by potential fricative

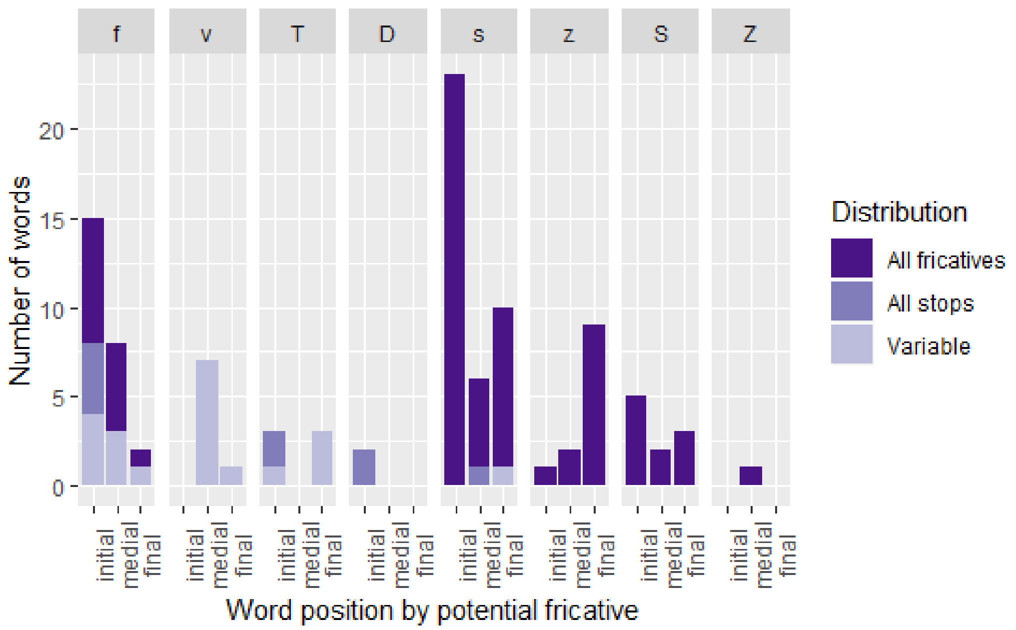


Note: T = /θ/, D = /ð/, S = /ʃ/, Z = /ʒ/

The stop-fricative variation here includes both inter- and intra-speaker variation. All tokens of potential /z, ʃ/, and /ʒ/ were realised as fricatives. The opposite is true for /ð/; in all words containing /ð/, /ð/ was realised entirely as a stop. In one third of words (2 out of 6) containing potential /θ/, realisations were entirely as stops, whilst the remainder varied. In all words with potential /v/, /v/ was realised with a combination of fricatives and stops. In 52% of words with /f/, was realised entirely as a fricative; in 16% it was realised entirely as a stop; and in 32% its realisation varied between stop and fricative. In 94.9% of words (37 out of 39) containing potential /s/, /s/ was realised as a fricative. One word, *pujiket* 'cat' (from ‘pussycat’), had /s/ realised only as a stop. In the remaining word, ‘horse’, /s/ was realised either as a fricative or a stop depending on whether it was articulated as [ɔ:s] or [u:ɹu] respectively, although there was also one token from speaker A43 that was pronounced more like [ɔ:t]. All other 9 tokens of ‘horse’ from A43 were realised as [ɔ:s].

Figure 8 shows that the number of different words containing each potential fricative in each word position (initial, medial, and final) varied greatly.

Figure 8 Distribution of stops and fricatives in Light Warlpiri words by word position and potential fricative

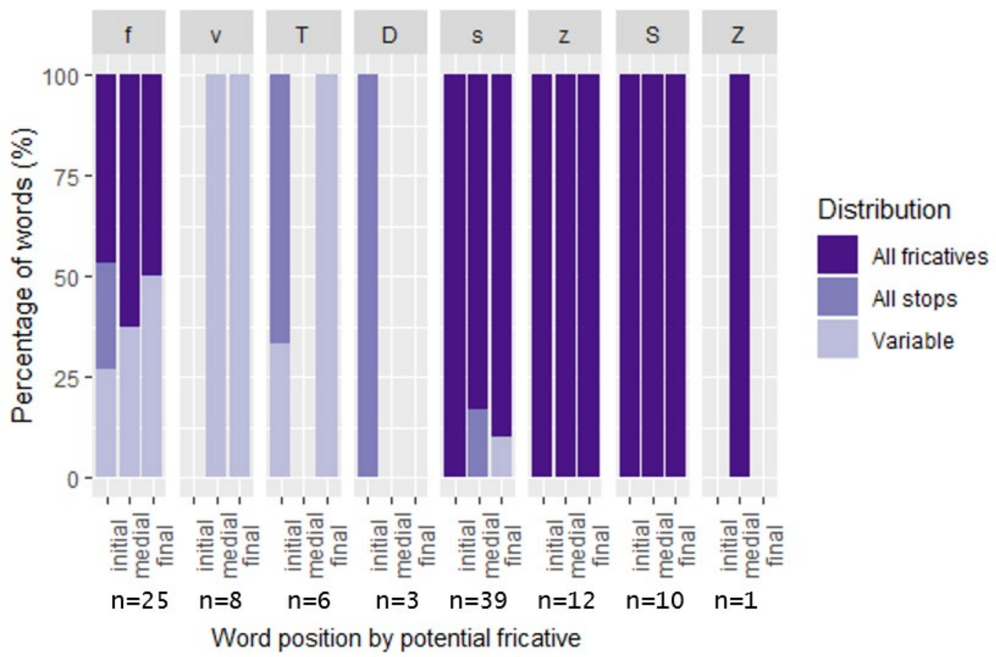


Note: T = /θ/, D = /ð/, S = /ʃ/, Z = /ʒ/

The data set lacks word-initial /v/ and /ʒ/, word-medial /θ/ and /ð/, and word-final /ð/ and /ʒ/. There were many more words containing word-initial /s/ (23 words) than any other combination of word-position and potential fricative. Word-initial /f/ was represented with the next greatest number of words at 15. There is only one word each containing word-final /v/ ('cave'), word-initial /z/ ('zoo') and word-medial /ʒ/ ('Casuarina').

This data is reconfigured in Figure 9 to show the percentage of the words for each word position-potential fricative combination that fall into each manner of articulation category.

Figure 9 Distribution of stops and fricatives as percentages in Light Warlpiri words by word position and potential fricative



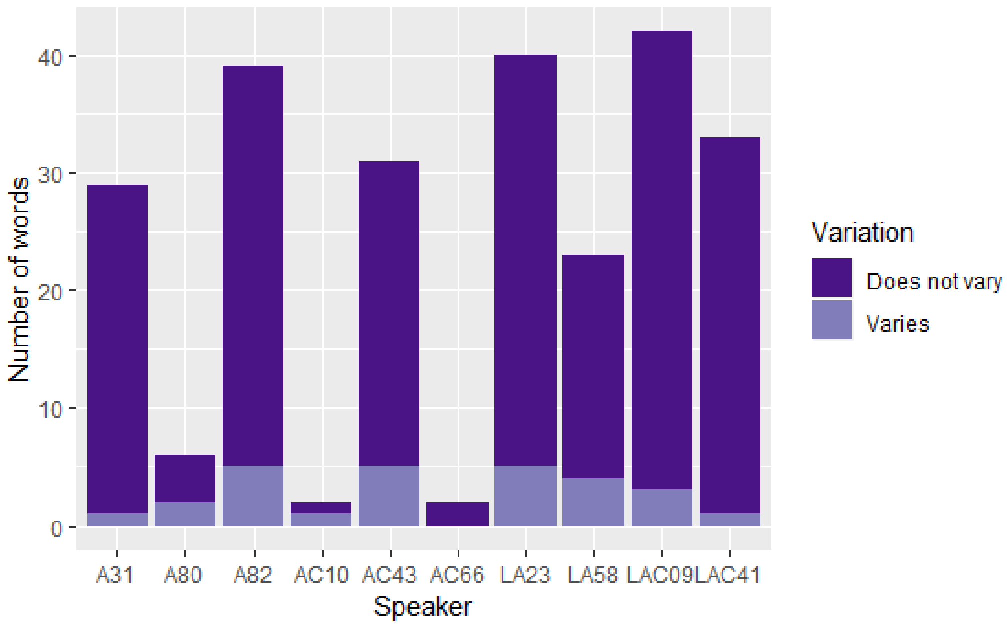
Note: T = /θ/, D = /ð/, S = /ʃ/, Z = /ʒ/

For all words with word-initial /s/, /s/ was realised as a fricative. In all words with word-final /θ/, /θ/ was realised both as a stop and as a fricative. Only one word with word-initial /θ/ ('thongs') shows variable production for /θ/. There are only two words containing word-final /f/ -

‘knife’ and ‘cough’. The /f/ in ‘cough’ was always realised as a fricative, but the realisation of /f/ in ‘knife’ was variable. 46.7% of words (7 of 15) with word-initial /f/ had fricative-only realisations, 26.7% (4 of 15) had stop-only realisations, and 26.7% (4 of 15) had variable realisation.

Figure 10 below shows the variability by speaker of those words that had multiple repetitions. The words in the lighter shade are those for which the speaker’s realisation of a potential fricative was a stop in one token and a fricative in another, at least once each.

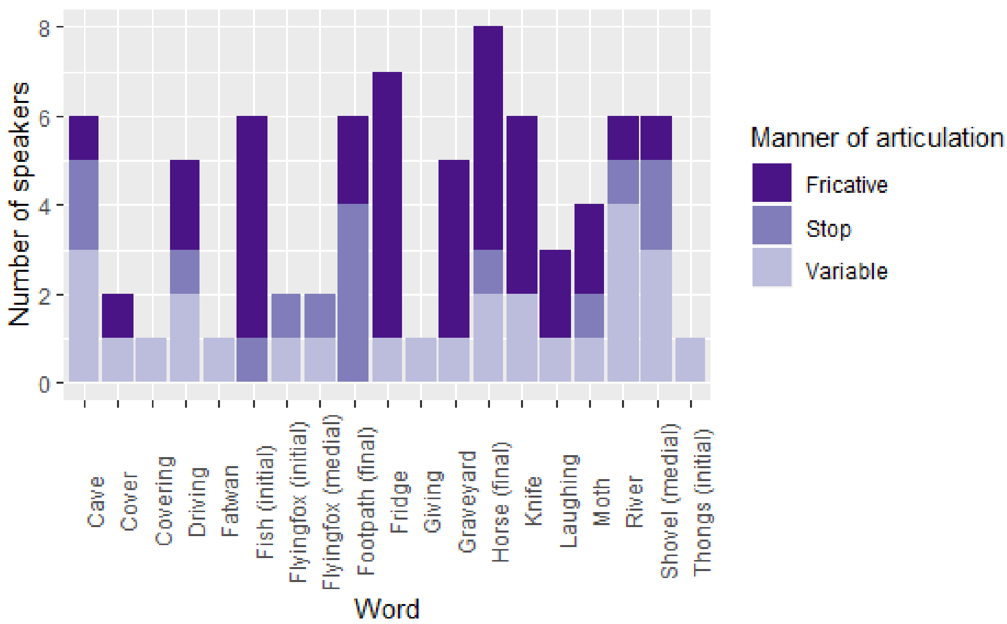
Figure 10 Variability of words by speaker



All speakers show stop-fricative variation in some words, except AC66 who contributes only two words with multiple tokens to the data set. Most words do not vary within speaker.

Those words that vary either across speaker or within speaker are shown in Figure 11 below. The number of speakers who use the word is given along the y-axis, and the shading indicates whether a particular speaker produced the potential fricative in all tokens of that word as a fricative, all as a stop, or whether they varied in their production.

Figure 11 Speaker manner of articulation for words with variable production

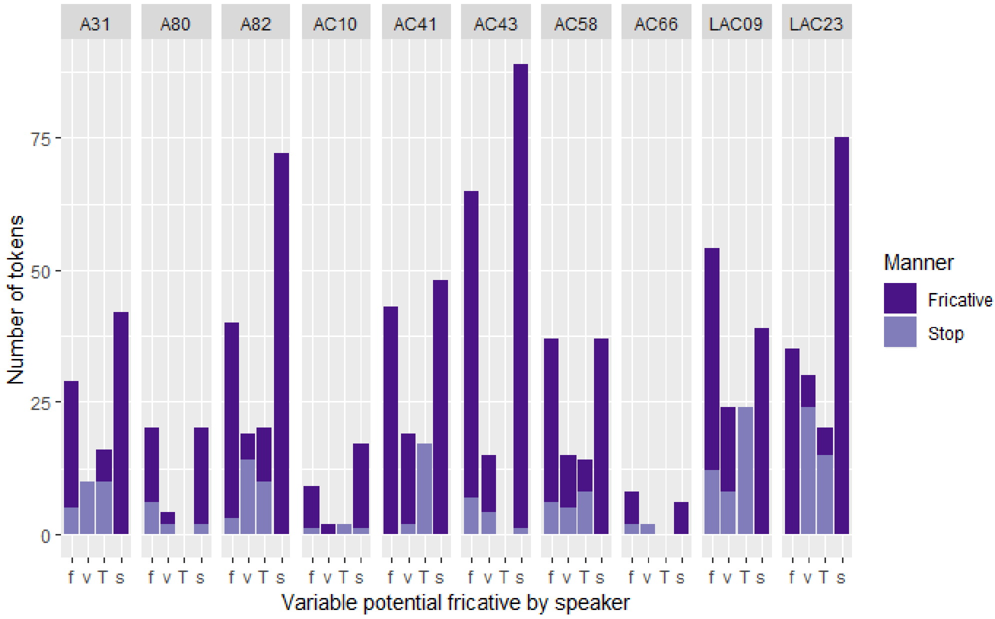


This shows that most potential fricatives for a specific word are produced variably by at least one speaker. There are some that vary only between speaker; for example, the /f/ in 'fish' is realised either as [b]ish or [f]ish but not as both by a single speaker. Likewise, speakers realised the /θ/ in 'footpath' either as a stop or as a fricative. 'River' had the most people producing variable realisations, with four participants realising it both as ri[b]er and as ri[v]er.

4.2.3 Variability by speaker

This section looks at the fricatives with variable distributions - /f, v, θ, s/ - and how their stop and fricative realisations vary by speaker and word position. An overview of the data is shown in Figure 12, and the same data is then presented per fricative.

Figure 12 Stop and fricative tokens for variable fricatives by speaker

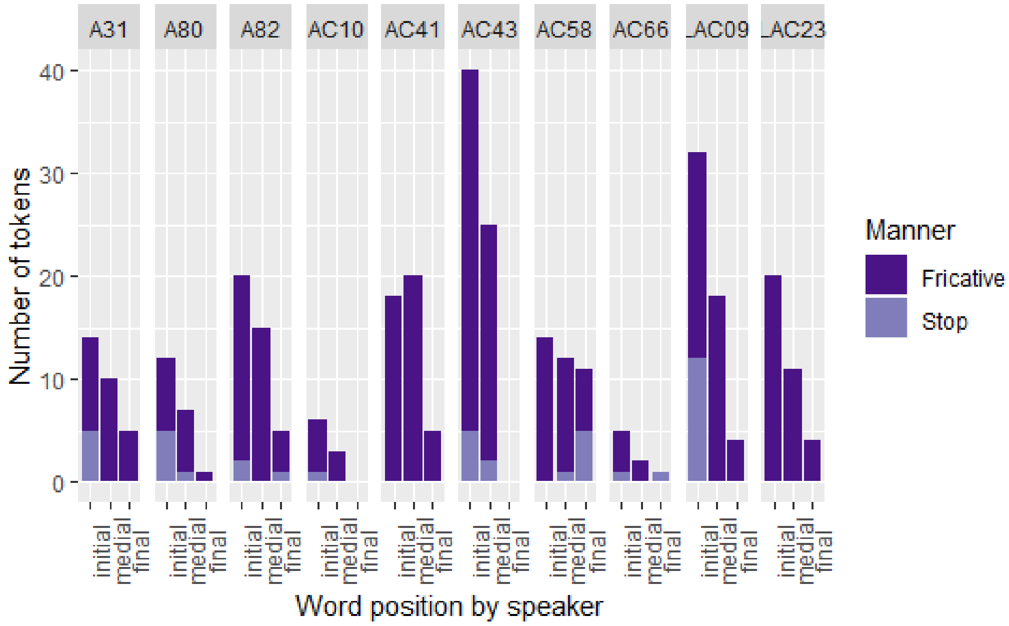


Note: T = /θ/

Potential /f/

Figure 13 shows the distribution of stop and fricative realisations for tokens of /f/ across all speakers. There were 340 tokens of potential /f/ in total.

Figure 13 Stop and fricatives tokens of /f/ by word position and speaker



Forty-two tokens (12%) were realised as stops, whereas 298 (88%) were not. Some speakers realised /f/ only as a fricative (LAC23, AC41). Three speakers (A31, LAC09, AC10) always realised /f/ as a fricative word medially and finally, but were variable with their pronunciation word-initially. Speaker AC58 appears to have the opposite pattern; realising every initial /f/ as a fricative, but medial and final /f/ variably. A82 and AC66 realised all medial /f/'s as fricatives, but gave some stop productions initially and finally. No speaker realised all tokens of /f/ as stops for any word position except AC66 word-finally, for which there was only one token. A summary of these patterns is given in Table 3.

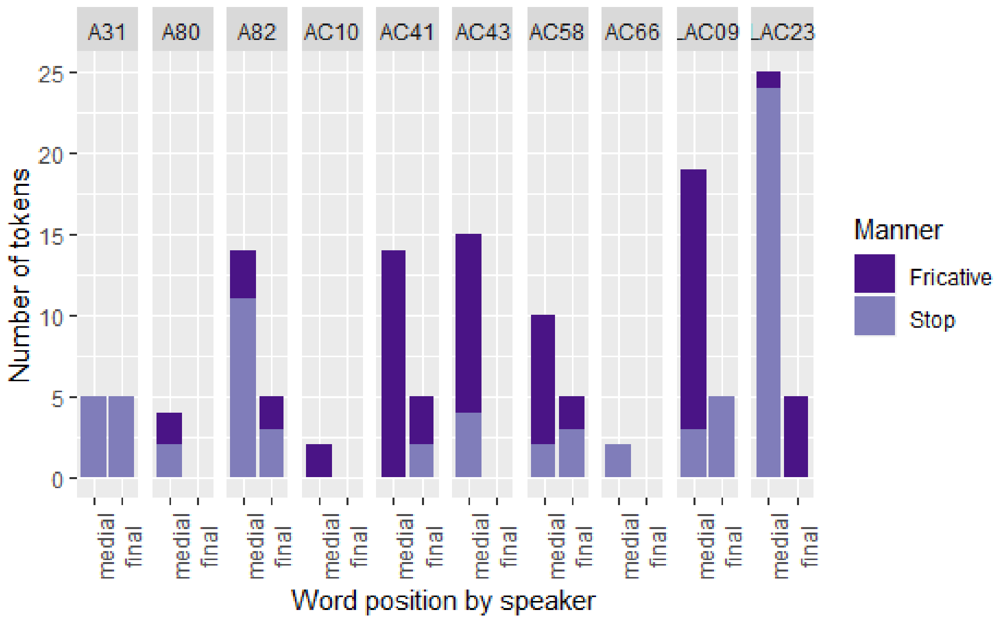
Table 3 Fricative and stop distribution patterns for /f/

Word initial	Word medial	Word final	Speakers
Fricative only	Fricative only	Fricative only	LAC23, AC41
Variable	Fricative only	Fricative only	A31, LAC09
Variable	Variable	Fricative only	A80
Variable	Fricative only	Variable	A82
Variable	Fricative only	-	AC10
Variable	Variable	-	AC43
Fricative only	Variable	Variable	AC58
Variable	Fricative only	Stop only	AC66

Potential /v/

Figure 14 shows the distribution of stop and fricative realisations for /v/ across all speakers. There were 140 tokens of potential /v/ in total.

Figure 14 Stop and fricative tokens for /v/ by word position and speaker



71 tokens (51%) were realised as stops whereas 69 (49%) were not. Several participants produced no word-final tokens of /v/, and there were no word-initial /v/'s in the data set. Some speakers realised /v/ only as stops (A31, AC66). Expect AC10, who provided only four word-medial

tokens, no speaker realised /v/ only as a fricative. For several speakers, the majority or all of word medial /v/'s were realised as fricatives (AC10, AC41, AC43, AC58, LAC09). For others, the majority of word medial /v/'s are realised as stops (A82, LAC23). Of those speakers that did produce word-final /v/, two realised them all as fricatives (A31, LAC09), three gave variable realisations (A82, AC41, AC58), and one realised them all as stops (LAC23). For the two speakers who provided the most tokens, LAC09 and LAC23, opposite patterns appear to be emerging. LAC09 tended to realise potential /v/ as a fricative word-medially and a stop word-finally, and LAC23 tended to realise potential /v/ as a stop word-medially and as a fricative word-finally. A summary of the patterns in /v/-realisation is given in Table 4.

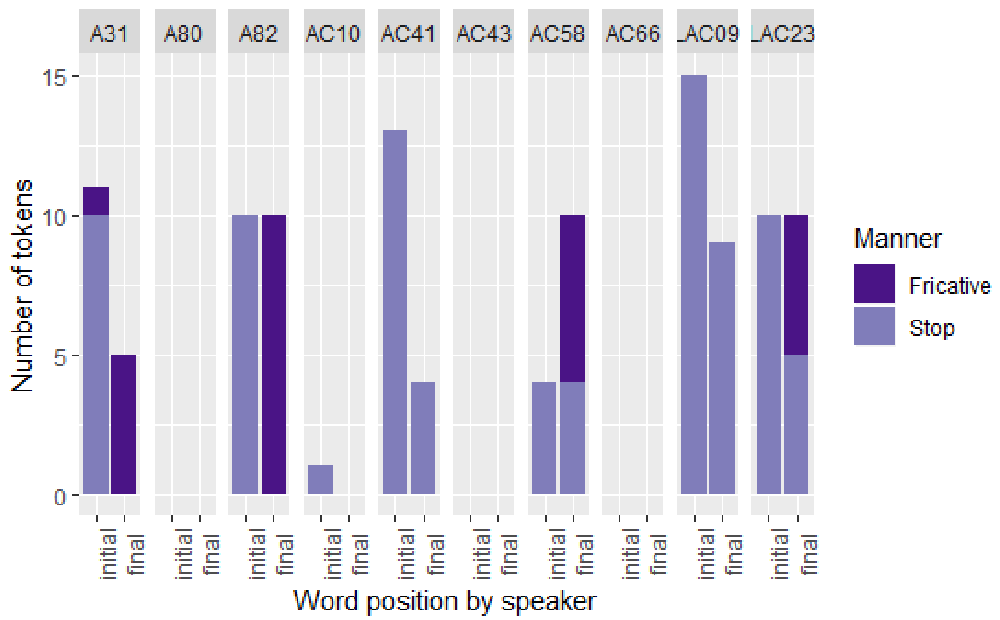
Table 4 Fricative and stop distribution patterns for /v/

Word medial	**Word final**	**Speakers**
Stop only	Stop only	A31
Variable	-	A80, AC43
Variable	Variable	A82, AC58
Fricative only	-	AC10
Fricative only	Variable	AC41
Stop only	-	AC66
Variable	Stop only	LAC09
Variable	Fricative only	LAC23

Potential /θ/

Figure 15 shows the distribution of stop and fricative realisations for /θ/ across all speakers. There were 113 tokens of potential /θ/ in total.

Figure 15 Stop and fricative tokens of /θ/ by word position and speaker



Several speakers contributed no tokens of /θ/ to the dataset (A80, AC43, AC66). Almost all word-initial /θ/'s are realised as stops, except for one token realised as a fricative by A31. Several speakers realised all tokens of /θ/as stops (AC41, LAC09). Others realised (almost) all initial /θ/ as stops but all final /θ/ as fricatives (A31, A82). Two speakers realised all word-initial /θ/ as stops, but varied for final /θ/ (AC58, LAC23). A summary of these patterns is given in Table 5. There was just one token of word-medial /θ/ in the dataset (not included in the figure above), realised as a stop in the word 'birthday'.

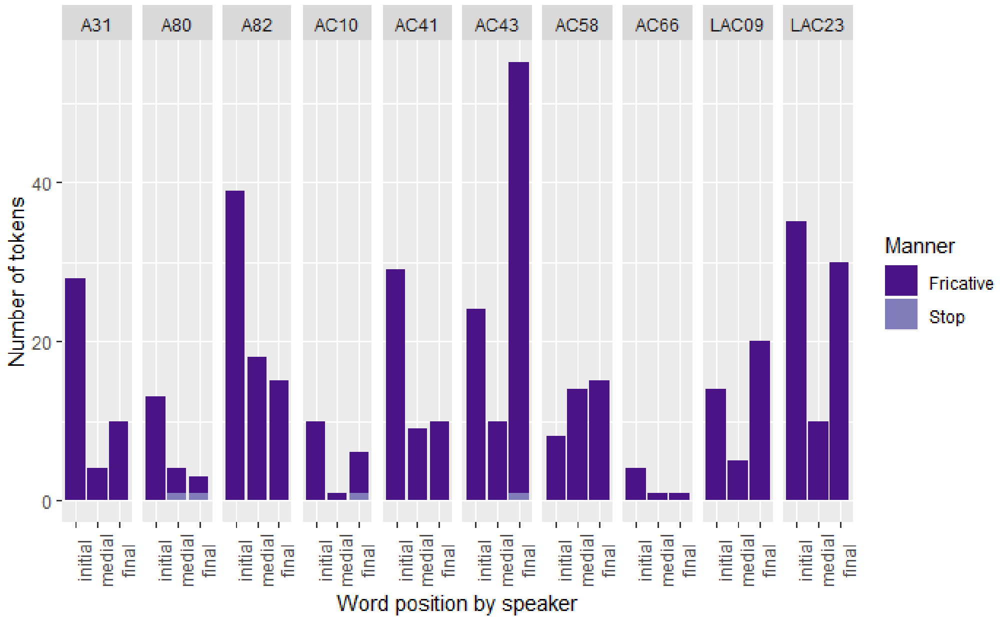
Table 5 Fricative and stop distribution patterns for /θ/

Word initial	**Word final**	**Speakers**
Stop only	Stop only	AC41, LAC09
Stop only	-	AC10
Variable	Fricative only	A31
Stop only	Fricative only	A82
Stop only	Variable	AC58, LAC23

Potential /s/

Figure 16 shows the distribution of stop and fricative tokens for /s/ across all speakers. There were 445 tokens of potential /s/ in total.

Figure 16 Stop and fricative tokens for /s/ by word position and speaker



All speakers produced tokens of /s/ in all word positions, and the vast majority of /s/ tokens were realised as fricatives. Thus, most speakers realised all tokens of potential /s/ as fricatives in all word positions. Only three participants (A80, AC10, AC43) realised /s/ as a stop. These realisations were in the words 'cat' and 'horse' as discussed in Section 4.2.2.

4.3 Discussion

4.3.1 Potential /h/

The results indicate that Light Warlpiri has no reflex of English word-initial /h/. With realisations present in just 6% of possible tokens, it appears that Light Warlpiri has undergone /h/-deletion from English. Instead, these words are vowel-initial, sometimes preceded by a glottal stop.

4.3.2 Potential /θ/ and /ð/

The data presented here provides evidence that, word-initially, potential dental fricatives in Light Warlpiri are produced as stops. All tokens of /ð/ and all but one token of word-initial /θ/ were produced as stops. This supports Bundgaard-Nielsen and O'Shannessy's (2019) inclusion of word-initial potential dental fricatives in their study of Light Warlpiri stops.

However, word-final /θ/ presents a different picture. Two speakers produced all word-final /θ/'s as fricatives, two produced them as all stops, and two produced them variably. This shows a lack of a conventionalised way of producing potential voiceless dental fricatives word-finally in Light Warlpiri. Of interest, the speakers who produced potential /θ/ entirely as a stop both word-initially and word-finally were the two second-generation Light Warlpiri speakers. This may be coincidental, or it may indicate a shift towards the realisation of potential /θ/ as a stop in all places of articulation. There were no tokens of potential /ð/ in any position other than word-initially, so the data cannot speak to how /ð/ is realised word-medially or word-finally. Word-medial /θ/ was also lacking.

Given that the production of potential /θ/ as a fricative is almost exclusively word-final, I propose that some speakers have [θ] as a word-final allophone of what is phonologically a dental stop, in keeping with Bundgaard-Nielsen and O'Shannessy's (2019) description of the presence of a dental stop in Light Warlpiri. This will need to be investigated in further research.

4.3.3 Potential /f/ and /v/

The data shows that potential /f/ and /v/ both had considerable stop-fricative variation. However, since Light Warlpiri speakers have been shown to be able to perceptually distinguish labiodental fricatives from bilabial stops (Bundgaard-Nielsen, O'Shannessy, & Baker, 2015), and the stop-fricative variability of potential /f/ and /v/ is found in every word position, I do not propose that these fricatives are allophones of phonological stops. Rather, the selection of a stop or a fricative in a given word may come down to a lexical decision. A Light Warlpiri speaker may have both English 'shovel' and Kriol *shabul* 'shovel' at their disposal and may switch between them. It may also or alternatively come down to a socially or linguistically motivated choice of pronunciation, perhaps where the use of a stop is more closely associated with traditional Aboriginal languages and a fricative is more closely associated with English. Sociophonetic research will be required to establish if this is indeed the case.

4.3.4 Potential /s/

Potential /s/ was produced as a fricative in all tokens except in the words for ‘cat’ and ‘horse’. Just 4 of 445 tokens (0.8%) were produced as stops. It is likely that the Light Warlpiri word for ‘cat’ comes from Kriol *pujiket* ‘cat’ and is an established lexeme. The productions of ‘horse’ can be divided into two groups, with one pronunciation that can be broadly transcribed as [ɔːs], which I shall write as *os,* and the other being [uːɟu], which O’Shannessy writes as *uuju* (O’Shannessy, 2006, p. 23). One speaker did produce one token of ‘horse’ as [ɔːt], but given that all other nine pronunciations by the same speaker were [ɔːs] and no other participant produced potential /s/ as [t], it would be more prudent to consider the [ɔːt] pronunciation as a speech irregularity rather than as evidence for general [s-t] variation. Since *uuju* follows the rules that would be expected for borrowing ‘horse’ into Warlpiri, and it occurs in both Warlpiri and Light Warlpiri in Lajamanu (O’Shannessy, personal communication, October 2019), I argue that it is an established lexeme in competition with *os*. If the source of Light Warlpiri *pujiket* and *uuju* are indeed Kriol *pujiket* and Warlpiri *uuju*, then these words cannot really be said to contain potential fricatives at all. Since the realisations of potential /s/ in all other words are fricatives, I argue that the Light Warlpiri reflex of English /s/ is a fricative.

4.3.5 Potential /z, ʃ/ and /ʒ/

Since all tokens of potential /z/, /ʃ/ and /ʒ/ are produced as fricatives, I conclude that reflexes of English postalveolar fricatives are fricatives in Light Warlpiri.

4.3.6 Summary

This study provides evidence for /h/-deletion in Light Warlpiri. It also suggests that the Light Warlpiri reflexes of English dental fricatives are stops, though potential voiceless dental fricatives have fricative allophones word-finally for some speakers. Reflexes of labiodental, alveolar, and postalveolar fricatives are all found to be produced as fricatives.

Chapter 5: Acoustic Characteristics Study

The purpose of the second study was to examine the acoustic characteristics of the realisations of potential fricatives in Light Warlpiri, in order to establish the presence or lack of place of articulation and voicing distinctions. Both English and Kriol distinguish labiodental, alveolar, and postalveolar fricatives, and English additionally distinguishes dental fricatives. Neither Kriol nor Aboriginal English have a voicing contrast in their fricative series, whereas English has a voiced-voiceless distinction for fricatives in all places of articulation (see fricative inventory summary at the end of section 1.1).

5.1 Data coding

Only potential fricatives that were realised as fricatives as determined in the first study were included in this study. As such, /h/ - which was only articulated in 6% of cases - and /ð/ - which was produced entirely as stops - were excluded from analysis. In order to control for the phonological environment, only intervocalic fricatives were used. Twenty-nine tokens were discarded due to background noise interference, such as the sound of the cards being handled. In total, 860 fricatives were included in this study. Contributions by speaker and by potential fricative segment were uneven, as shown in Table 6 and Table 7.

Table 6 Number of tokens by speaker contribution

Speaker code	Number of tokens
A31	73
A80	16
A82	158
AC10	17
AC41	101
AC43	119
AC58	93
AC66	2
LAC09	158
LAC23	123

Table 7 Number of tokens by potential fricative contribution

Potential fricative	Number of tokens
/f/	205
/v/	58
/θ/	17
/s/	189
/z/	145
/ʃ/	227
/ʒ/	19

Fricatives were analysed using Praat (Boersma & Weenink, 2019). The onset of the fricative was defined as the start of high-frequency energy and/or irregular sound waves, and the offset was defined as the zero-crossing before the onset of the regular periodicity of the following vowel. The author's boundary judgements were evaluated by an experienced phonetician for a subset of the data (58 tokens), with 98% agreement. The disagreement over one token was due to interference from a page turn at the onset of the fricative, and the token was discarded.

The values for the first four spectral moments – mean frequency, standard deviation of the frequency, skewness, and kurtosis – were obtained for each fricative (discussed in section 2.3). Values were averaged over the duration of the fricative, using pre-emphasis of

6dB/octave and 40ms Gaussian windows. The average intensity of the fricative and the following vowel were also obtained, as was the duration of the fricative. Normalised intensity was determined by subtracting the vowel intensity from the fricative intensity.

The length of detectable pitch for the left and right edges of the fricatives was also recorded. It was considered whether to use the raw fricative duration or normalised duration, which is the duration of the fricative as a proportion of the length of the word. Normalising the duration helps control for speaking rate. However, its use was rejected due to the discrepancy in the length of words in the data; words range from only one syllable (e.g. 'zoo', 'knife', 'thongs') to four (e.g. 'Casuarina').

Three measures of voicing were obtained through manipulation of the data. These were introduced in section 3.2, but some of the description is repeated here for clarity.

The first measure was the proportion of the fricatives that were voiced. This was obtained for each fricative by dividing the duration of detectable pitch by total duration. This measure has a range from zero (the fricative has no detectable pitch) to one (the fricative has detectable pitch throughout).

The second voicing measure is a binary variable with the two levels 'voiced' and 'voiceless'. A fricative was labelled 'voiceless' if the duration of voicing at either the left or right edges or both exceeded 30 ms, regardless of the total duration of the fricative. Fricatives with voicing durations at both edges equal to or shorter than this cut-off were labelled ‘voiceless’.

The third voicing measure is also a binary variable with the two levels ‘voiced’ and ‘voiceless’. The total time for which a fricative lacked voicing was obtained by subtracting the duration of detectable pitch from the total duration of the fricative. A fricative was labelled ‘voiceless’ if the length of detectable pitch exceeded 60ms, regardless of the total duration of the fricative, and fricatives with values equal to or less than this were labelled ‘voiced’.

A summary of the dependent variables and the terms used for them is given in Table 8 below.

Table 8 Summary of the terms for the dependent variables under investigation

duration	Total duration of the fricative measured in seconds.
proportion.voiced	The total duration with detectable pitch divided by the total duration of the fricative. Ranges from 0 to 1.
duration.voiced	Binary variable with levels ‘voiced’ and ‘voiceless’ depending on whether the duration of detectable pitch at the left or right edge of the fricative exceeds 30ms.
duration.voiceless	Binary variable with levels ‘voiced’ and ‘voiceless’ depending on whether the duration without detectable pitch exceeds 60ms.
mean	The mean frequency of the fricative (the first spectral moment). Measured in hertz.
st.dev	The standard deviation of the fricative (the second spectral moment). Measured in hertz.
skew	The skewness of the fricative (the third spectral moment).
kurtosis	The kurtosis of the fricative (the fourth spectral moment).
norm.int	The normalised intensity measured as the intensity of the fricative minus the intensity of the following vowel. Measured in decibels.

5.2 Data analysis

To analyse the data, linear mixed-effects models and generalised linear mixed-effects models were created using the *lmer* and *glmer* functions in the *lme4* package in RStudio (Bates et al., 2019). A model for each independent variable model was produced with *speaker* and *word* as non-nested random effects and *segment* with levels 'f', 'v', 'T' (for /θ/), 's', 'z', 'esh' (for /ʃ/) and 'ezh' (for /ʒ/) as a main effect. For all independent variables except the voicing variables, another model was produced with *speaker* and *word* as non-nested random effects and *POA* (place of articulation) with levels 'labiodental', 'dental', 'alveolar', and 'postalveolar'. This was done in case there is no voicing contrasts in Light Warlpiri, which would necessitate /f-v/, /s-z/, and /ʃ-ʒ/ pairs being considered together as one fricative each.

For the voicing variables, linear and generalised mixed-effects models were created within each place of articulation grouping (i.e. to compare potential /s/ with /z/, /f/ with /v/ and /ʃ/ with /ʒ/). For labiodental and postalveolar pairs, these models were first tested with an interaction between *segment* and *word.position* as main effects, and were subsequently pruned until all main effects were significant predictors. This was necessary since the potential voiced fricative in each voiceless-voiced pair lacked word-initial tokens (e.g. there were no word-initial potential /v/ tokens but many word-initial potential /f/ tokens). Only medial fricatives were included in the models for the postalveolar fricatives, as /ʒ/ was only present in the data word-medially. Thus, no main effect of *word.position* was tested for postalveolar fricative voicing.

Post hoc analyses were conducted using the *anova* function in the *lmertest* package (Kuznetsova, Brockhoff, & Christensen, 2019), the *emmeans* and *pairs* functions in the *emmeans* package (Lenth, Singmann, Love, Buerkner, & Harve, 2019), and the *lrtest* function in the *lmtest* package (Hothorn, Zeileis et al., 2019). Graphs were plotted using the *ggplot* function in the *ggplot2* package (Wickham, Chang, et al., 2019). The outputs for all models can be found in Appendix B.

For each dependent variable, a conditional inference tree (c-tree) and a variable importance ranking were created in RStudio (R Core Team, 2019) using the *ctree* function of the *party* package (Hothorn, Hornik, Strobl, & Zeileis, 2019). C-trees show the significant splits in the data (α = .05). They cannot account for random variation like a linear mixed-effects model can, but they deal well with correlated variables and non-linear relationships. Tagliamonte and Baayen (2012) recommend their use for establishing an overview of the interactions in the data. Random forests, invented by Breiman (2001), are used to rank the relative importance of dependent variables in the data. Briefly, random forests involve the testing of many c-trees based on subsets of the data taken. The trees 'vote' on which variables they find to be the most important predictors, and the output is a variable importance ranking (see Strobl, Malley, & Tutz, 2012 and Tagliamonte & Baayen, 2012 for more on conditional inference trees and random forests). These tools allow the inclusion of the vowel formant information, which led to overfitting when their interactions were included in the linear mixed-effects models.

However, because vowel formants proved to be some of the least important variables overall (§5.3.10), and the individual c-trees should not be given as much weight as mixed-effects models, I have included only the c-trees for *skew* and *kurtosis* in the text, since these variables could not be transformed to meet the assumptions of a linear mixed-effects model. The c-trees for the variables that could also be modelled using mixed-effects modelling have been appended in Appendix C. The variable rankings for each dependent variable have been included in the text.

The independent variables under consideration for the c-trees and the random forests were *segment* with seven levels 'f', 'v', 'T' (for /θ/), 's', 'z', 'esh' (for /ʃ/) and 'ezh' (for /ʒ/); *word.position* with three levels 'initial', 'medial', and 'final'; *englishVoicing* with two levels 'voiced' and 'voiceless', and *prevF1, prevF2, follF1, follF2* – the average values of the first and second formants for the preceding and following vowels respectively. If a particular variable is not shown in a conditional inference tree, it is because no split within it reaches significance.

5.3 Results

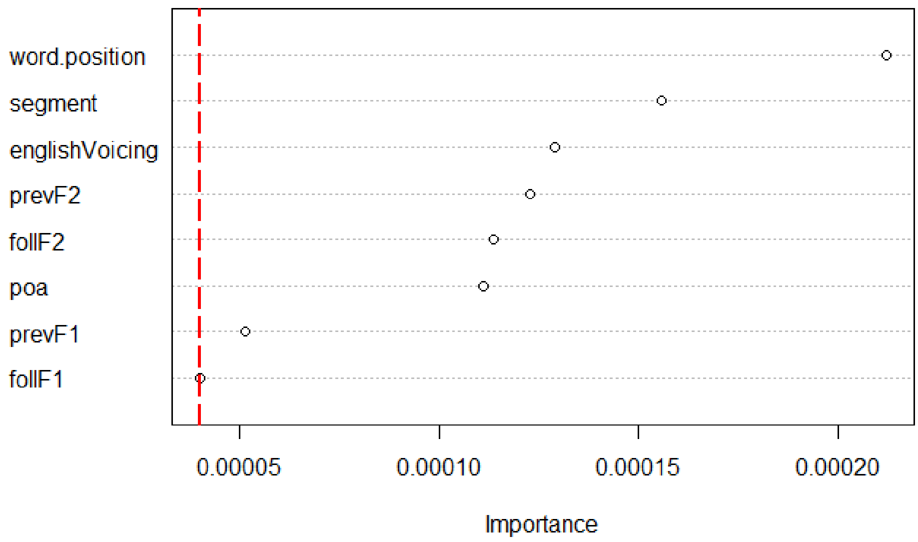
5.3.1 Duration

A linear mixed effects model with *duration* as a dependent variable, *segment* as a main effect, and *speaker* and *word* as random effects showed that the segment type (i.e. whether it was potential /f/, potential /v/, potential /s/ and so on) was a significant predictor of the duration of a fricative ($p < .001$). A post hoc analyses showed /v/ to be shorter than /f/ ($p < .01$), /s/ ($p < .001$) and /ʃ/ ($p < .001$). The difference between /ʃ/ and /θ/ approached significance ($p = .052$), with /ʃ/ being longer, as did the difference between /s/ and /z/ ($p = .059$), with /s/ being longer. No other contrasts reached significance.

A linear mixed-effects model with *duration* as a dependent variable, *POA* (place of articulation) as a main effect, and *speaker* and *word* as random effects shows that place of articulation was a significant predictor of the duration of a fricative ($p < .01$). A post hoc analysis showed dental fricatives to be shorter than alveolar fricatives ($p = .047$) and postalveolar fricatives ($p < .01$). The difference between labiodental and postalveolar fricatives approached significance ($p = .055$) with labiodentals being shorter. No other contrasts reached significance.

Figure 17 shows the variable importance ranking for duration as determined by a random forest analysis. Anything at or to the left of the left line is unimportant, and the importance of the variables decreases as the chart is read from top to bottom. The word position was thus the most important variable influencing duration, followed by segment. Whether or not the fricative is voiced in English was secondary, followed by the F2 values of the previous and following vowels. Place of articulation was next important after that, followed by the F1 value of the previous vowel. The F1 value of the following vowel was unimportant.

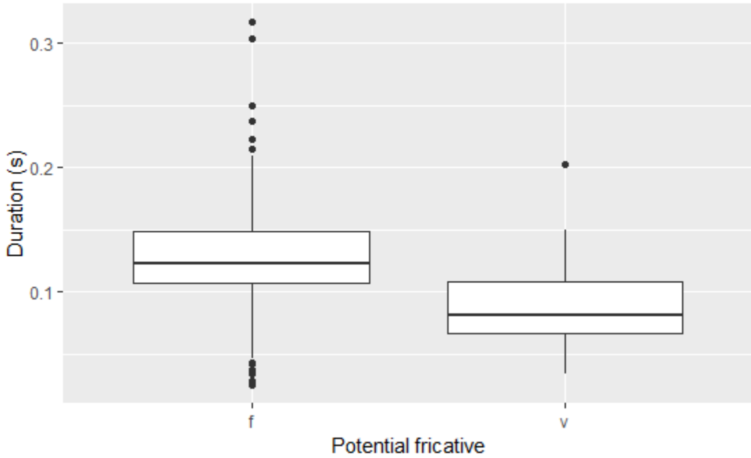
Figure 17 Variable importance for duration of fricatives



Labiodental

Taking just labiodental fricatives, a linear mixed-effects model with *duration* as a dependent variable, *segment* as a main effect, and *speaker* and *word* as random effects showed that segment was a significant predictor of fricative duration (p = .001). The inclusion of *word.position* as a main effect did not improve the model. A post hoc analysis showed that /f/ is significantly longer than /v/ (p = .001) (see Figure 18).

Figure 18 Duration of potential labiodental fricatives



Alveolar

Taking just potential alveolar fricatives, a linear mixed-effects model with *duration* as a dependent variable, *word.position* as a main effect, and *speaker* and *word* as random effects showed that the position in the word was a significant predictor of the duration of the alveolar fricative ($p < .001$). The inclusion of *segment* did not improve the model (see Figure 19). A post hoc analysis showed initial ($p < .001$) and final ($p = .022$) alveolar fricatives to be longer than medial alveolar fricatives, but the difference between final and initial alveolar fricative durations was non-significant ($p = .306$) (see Figure 20).

Figure 19 Duration of potential alveolar fricatives

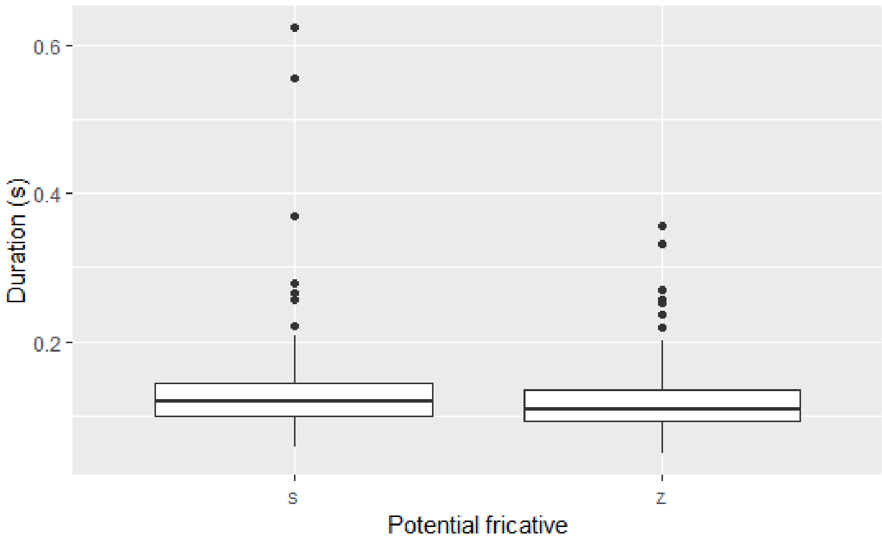
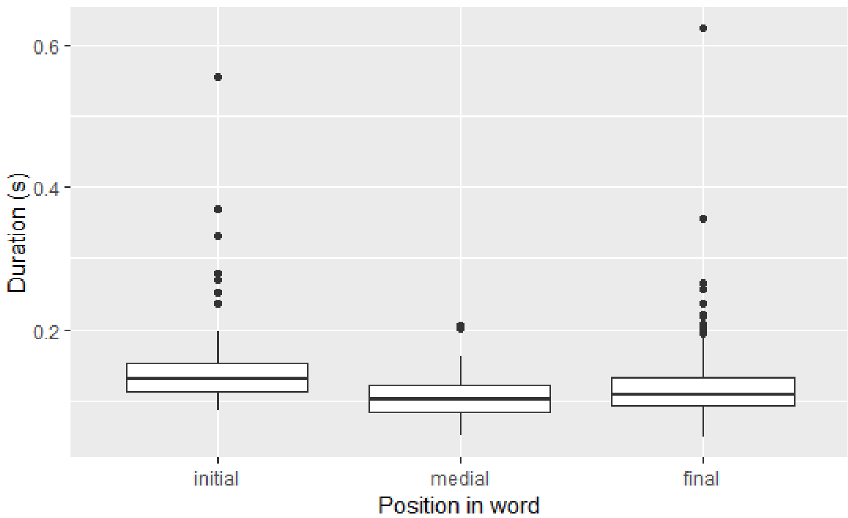


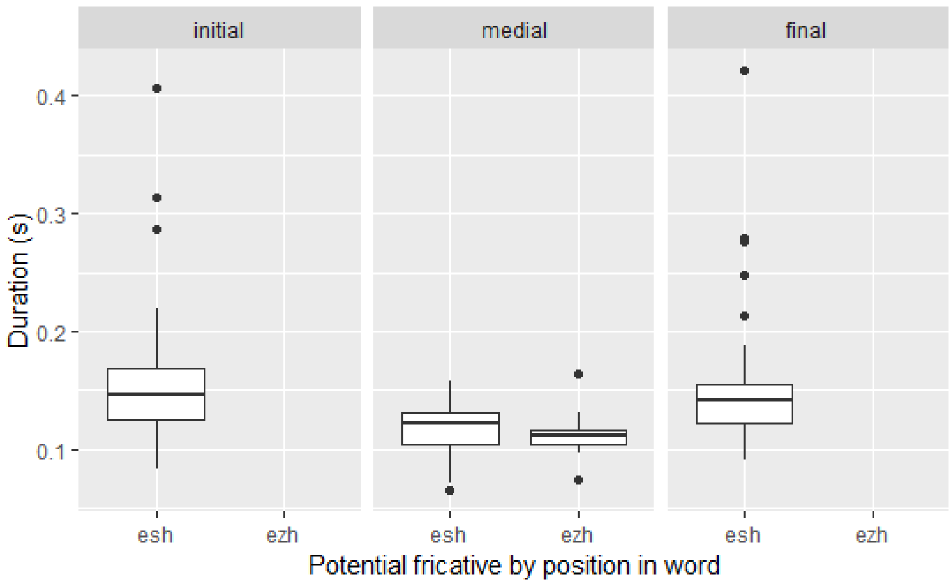
Figure 20 Duration of potential alveolar fricatives by position in word



Postalveolar

Using only data from word-medial potential postalveolar fricatives, a linear mixed-effects model with *duration* as a dependent variable, *segment* as a main effect, and *speaker* and *word* as random effects showed that the segment type was not a significant predictor of the duration of the fricative (p = .33) (see Figure 21).

Figure 21 Duration of potential postalveolar fricatives by position in word

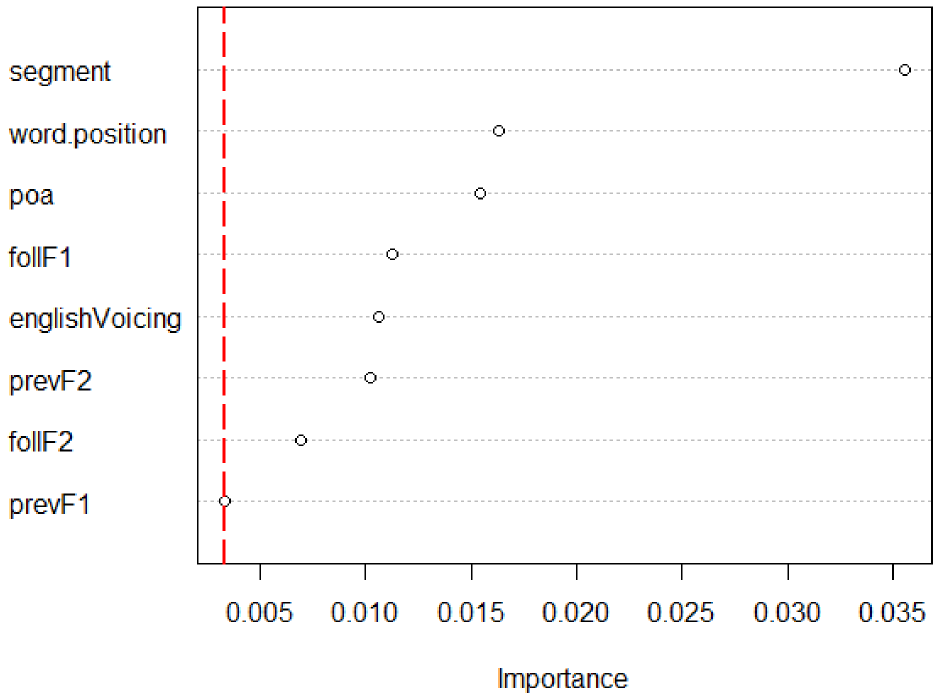


Note: esh = /ʃ/, ezh = /ʒ/

5.3.2 Voicing test 1: proportion voiced

Figure 22 shows the variable importance ranking for *proportion.voiced* as determined by a random forest analysis. The segment type of the fricative was the most important variable influencing the proportion of detectable pitch the fricative had, followed by its position in the word. Place of articulation was secondary. Whether or not the fricative is cognate with a voiced fricative in English was less important, as only the 5^{th} most important variable.

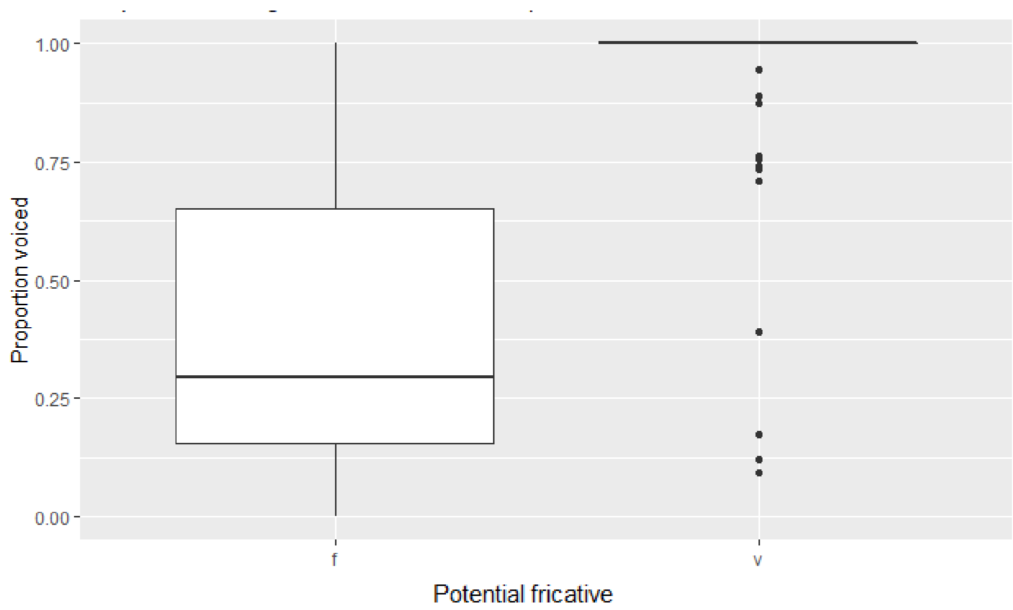
Figure 22 Variable importance for proportion voiced



Labiodental

Taking just the potential labiodental fricatives, a linear mixed-effects model with *proportion.voiced* as a dependent variable, *segment* as a main effect, and *speaker* and *word* as random effects showed that segment was a significant predictor of the proportion of the fricative with detectable pitch ($p < .001$, see Figure 23). The inclusion of *word.position* did not improve the model. A post hoc analysis showed /v/ to have a significantly higher proportion of voicing than /f/ ($p < .001$).

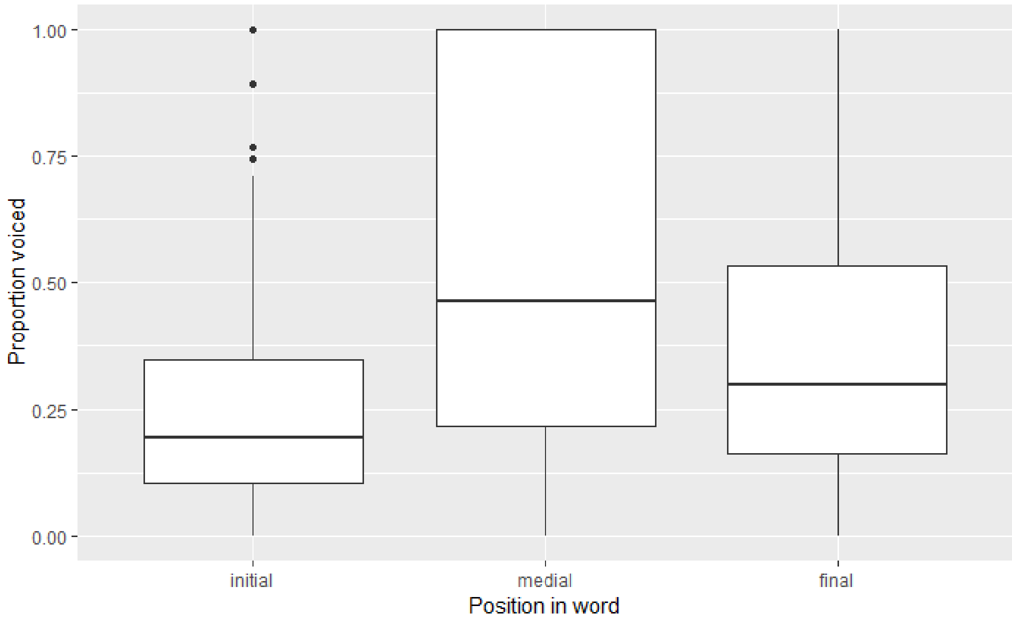
Figure 23 Proportional fricative voicing for potential labiodental fricatives



Alveolar

Taking just potential alveolar fricatives, linear mixed effect model with *proportion.voiced* as a dependent variable, *word.position* as a main effect, and *speaker* and *word* as random effects showed that the position in the word (initial, medial, or final) of a fricative was a significant predictor of the proportion of the fricative with detectable voicing (p = .001, see Figure 24). The inclusion of *segment* as a main effect did not improve the model. Both medial (p =.001) and final (p = .048) alveolar fricatives were found to have a greater proportion of voicing than initial fricatives.

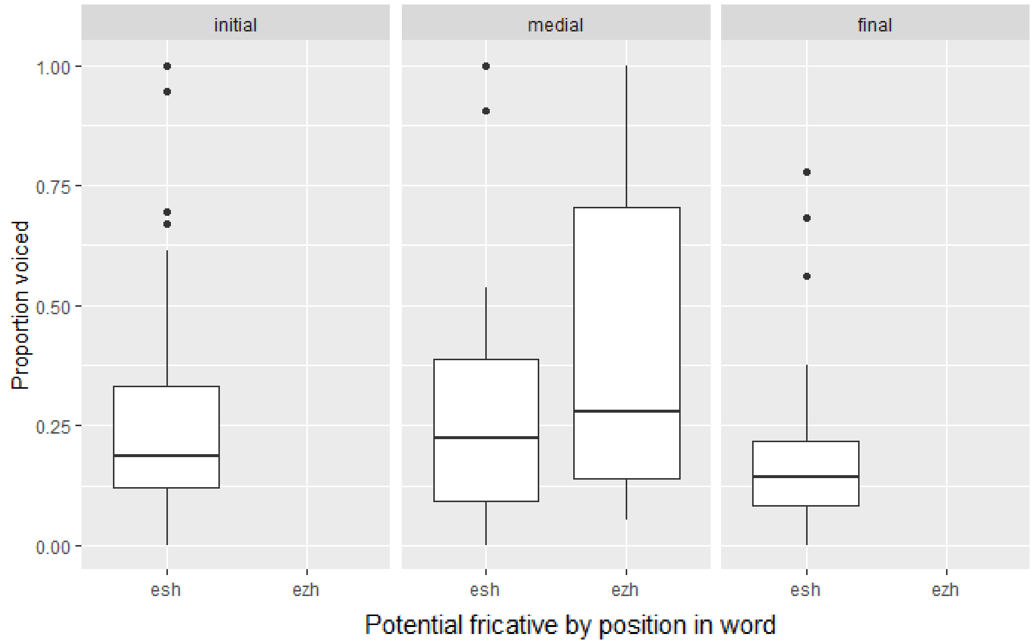
Figure 24 Proportion of fricative voiced for potential alveolar fricatives by word position



Postalveolar

Taking just the word-medial potential postalveolar fricatives, a linear mixed-effects model with *proportion.voiced* as a dependent variable, *segment* as a main effect, and *speaker* and *word* as random effects showed that segment was not a significant predictor of the proportion of the fricative with detectable pitch ($p = .144$) (see Figure 25).

Figure 25 Proportional fricative voicing for potential postalveolar fricatives by position in word

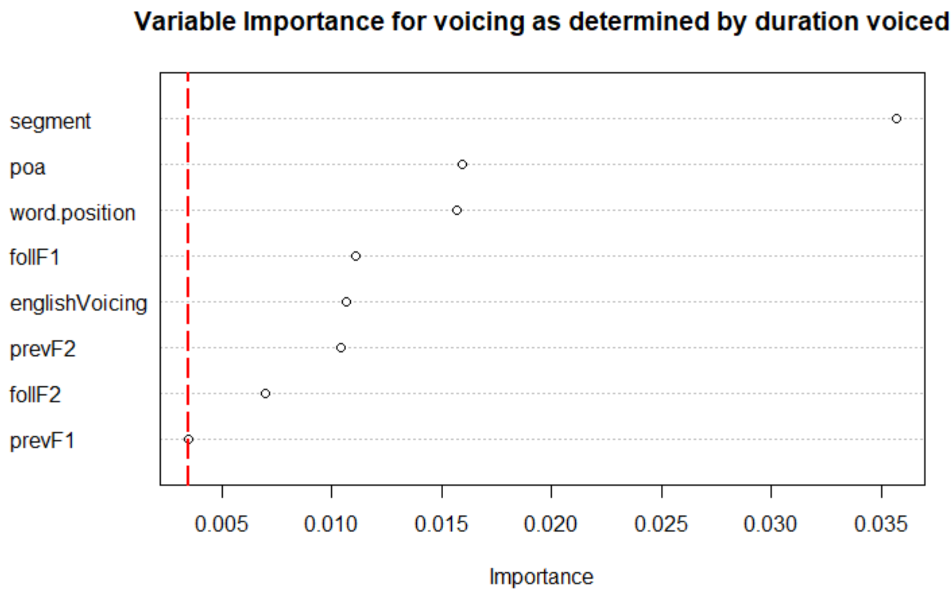


Note: esh = /ʃ/, ezh = /ʒ/

5.3.3 Voicing test 2: duration voiced

Figure 26 shows the variable importance ranking for *duration.voiced* as determined by a random forest analysis. The segment type of the fricative was the most important variable influencing whether the fricative was classified as voiced or voiceless by the *duration.voiced* measure. Next most important were the place of articulation and the position in the word. Whether or not the fricative is cognate with a voiced fricative in English was again less important, as only the 5^{th} most important variable.

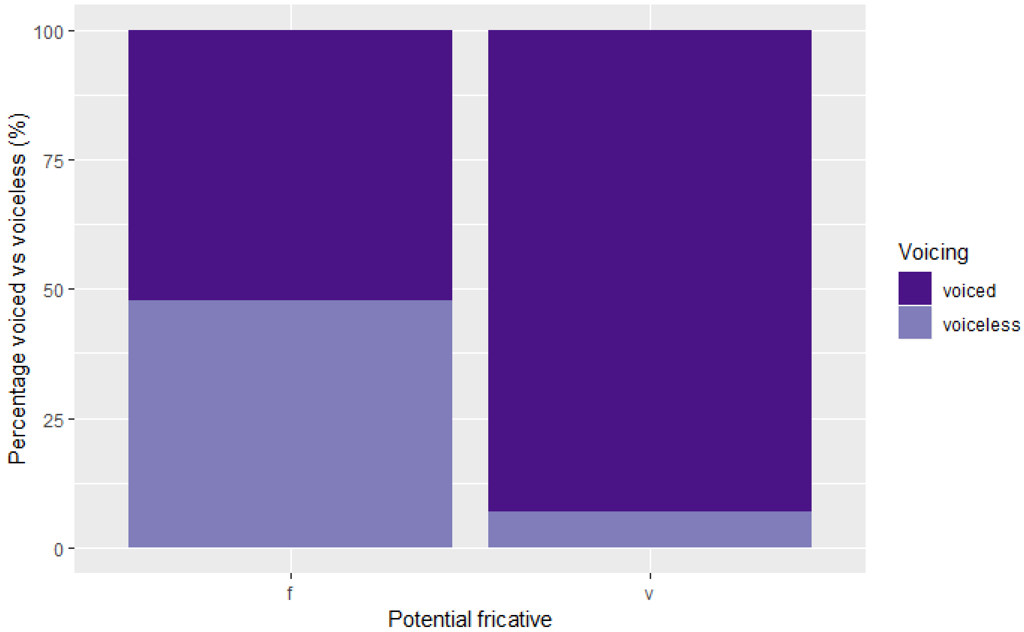
Figure 26 Variable importance for voicing as determined by duration voiced measure



Labiodental

Figure 27 below shows the percentage of tokens for each potential labiodental fricative identified as voiced and voiceless by the *duration.voiced* measure. Generalised linear mixed effect models with *duration.voiced* as a dependent variable and *speaker* and *word* as random effects were fitted. A likelihood ratio test showed that the inclusion of *segment* as a main effect in the model provided a better fit to the data than without (χ^2 (1) = 8.28, p = .004). A post hoc analysis showed potential /v/ to be voiced significantly more than potential /f/ (p = .008).

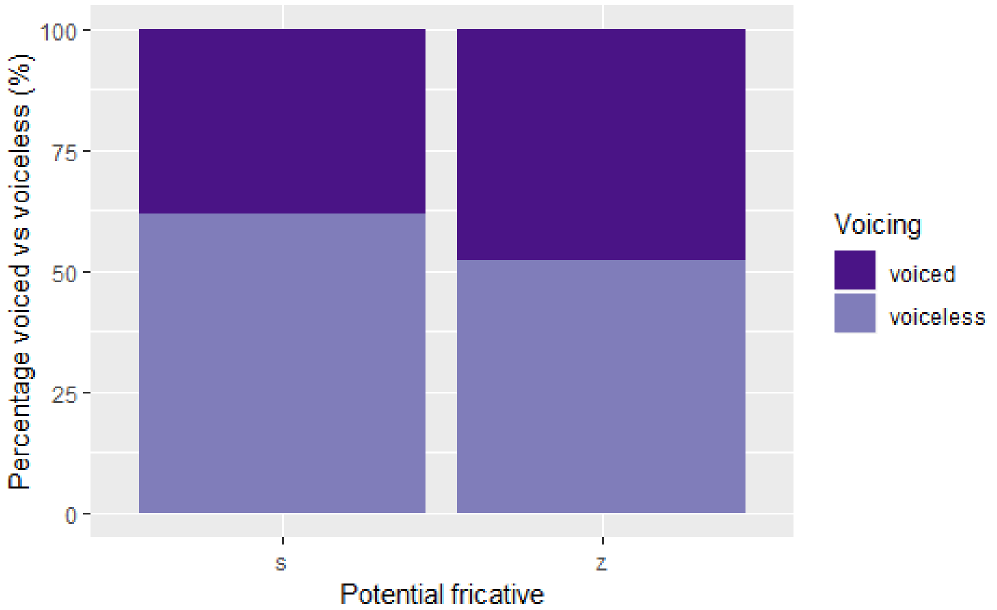
Figure 27 Percentage of potential labiodental fricatives voiced and voiceless according to duration voiced measure



Alveolar

Figure 28 below shows the percentage of tokens for each potential alveolar fricative identified as voiced and voiceless by the *duration.voiced* measure. Generalised linear mixed effect models with *duration.voiced* as a dependent variable and *speaker* and *word* as random effects were fitted. Likelihood ratio tests showed that neither the inclusion of *word.position* (χ^2 (2) = 4.56, p = .10) nor *segment* (χ^2 (1) = 1.87, p = .17) as main effects improved the fit of the model to the data.

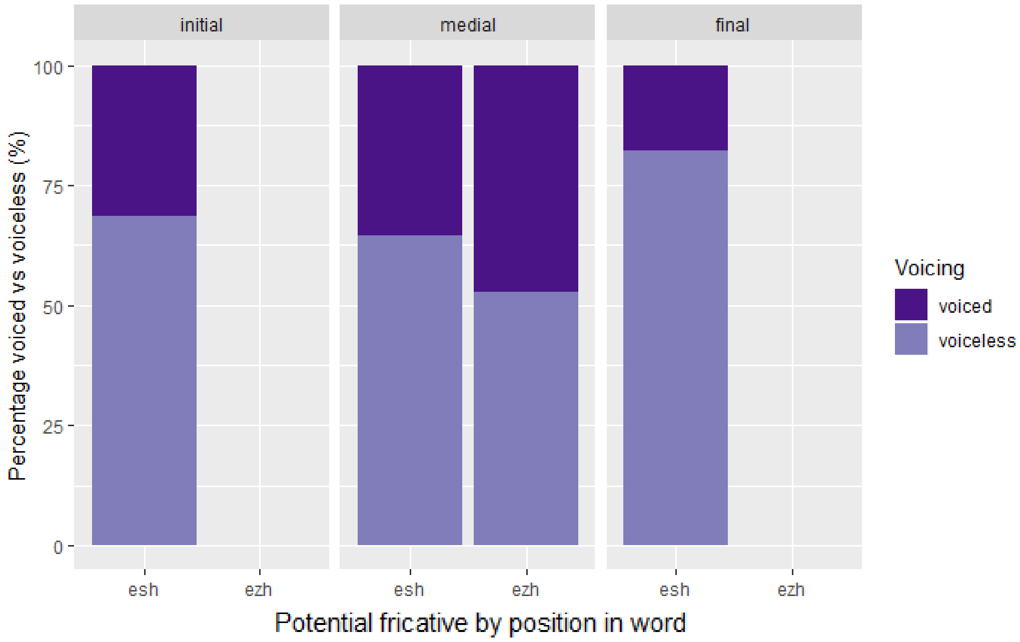
Figure 28 Percentage of potential alveolar fricatives voiced and voiceless according to duration voiced measure



Postalveolar

Figure 29 below shows the percentage of tokens for each potential fricative identified as voiced and voiceless by the *duration.voiced* measure. Taking just the word-medial potential postalveolar fricatives, generalised linear mixed effect models with *duration.voiced* as a dependent variable and *speaker* and *word* as random effects were fitted. Likelihood ratio tests showed that the inclusion of *segment* as a main effect did not improve the fit of the model to the data (χ^2 (1) = 3.36, p = .07).

Figure 29 Percentage of potential postalveolar fricatives voiced and voiceless by position in word according to duration voiced measure

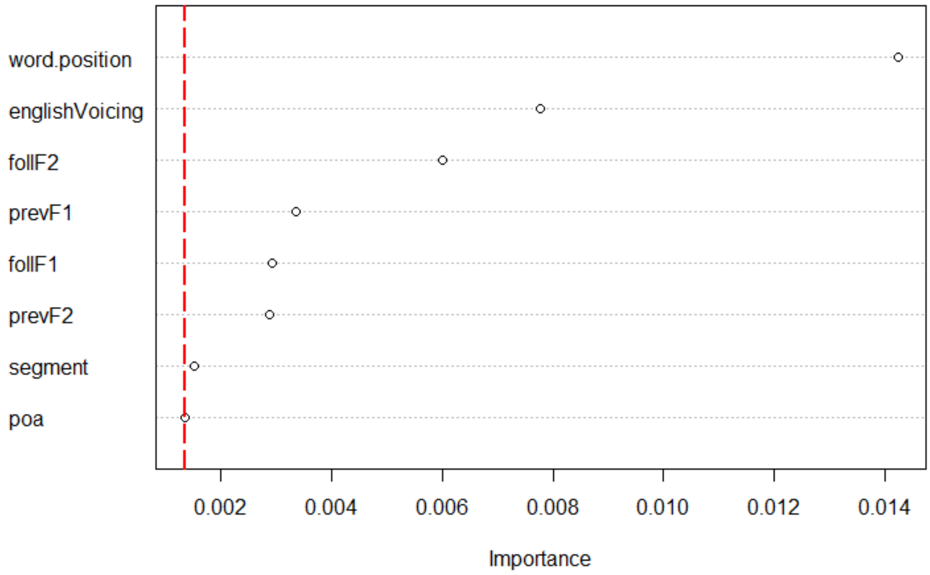


Note: esh = /ʃ/, ezh = /ʒ/

5.3.4 Voicing test 3: duration voiceless

Figure 30 shows the variable importance ranking for *duration.voiceless* as determined by a random forest analysis. The position in the word of the fricative was the most important variable influencing whether the fricative was classified as voiced or voiceless by the *duration.voiceless* measure. Next most important was whether or not the fricative is cognate with a voiced fricative in English. The segment type and place of articulation were unimportant for this variable.

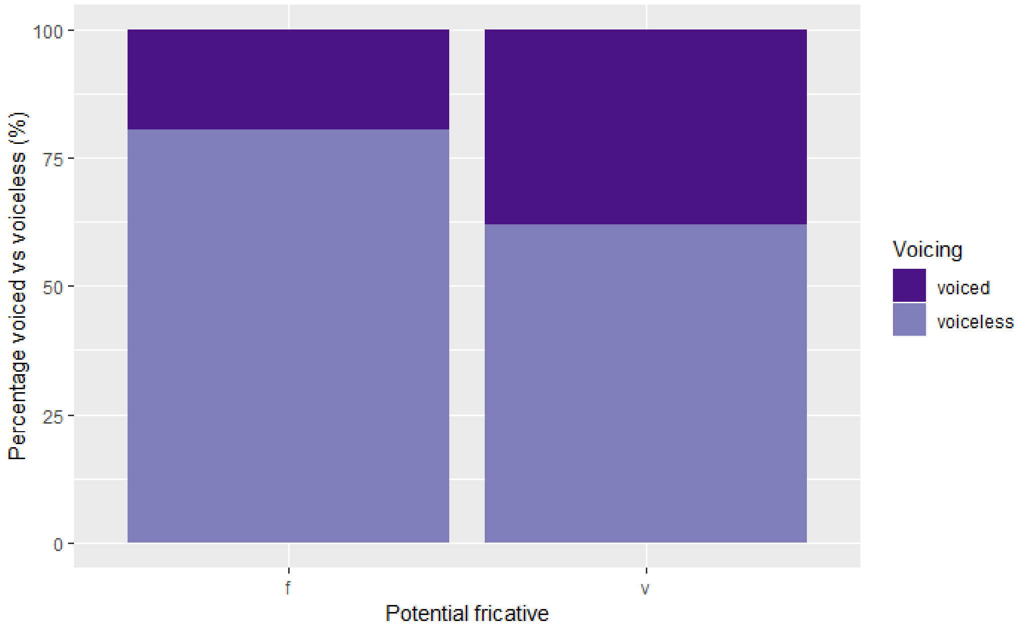
Figure 30 Variable importance for voicing as determined by duration voiceless measure



Labiodental

Figure 31 shows the percentage of the tokens for /f/ and /v/ that were considered voiced or voiceless by the *duration.voiceless* measure. Generalised linear mixed-effects models were fitted with *duration.voiceless* as a dependent variable, and *speaker* and *word* as dependent variables. Likelihood ratio tests showed that neither the inclusion of *word.position* (χ^2 (2) = 5.04, p = .08) nor *segment* (χ^2 (1) = 2.66, p = .10) improved the fit of the model.

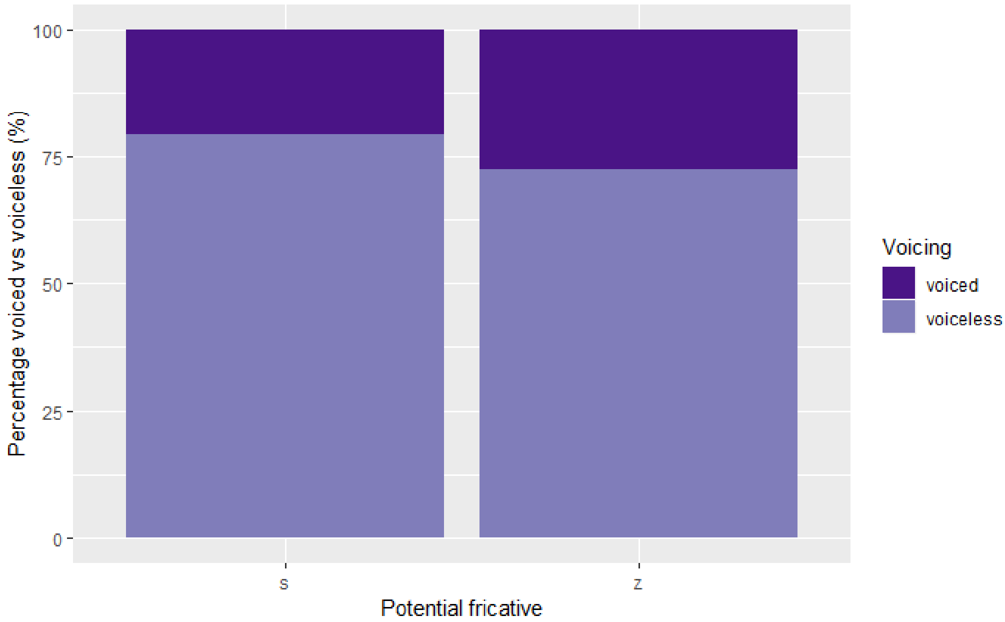
Figure 31 Percentage of potential labiodental fricatives voiced and voiceless according to duration voiceless measure



Alveolar

Figure 32 shows the percentage of the tokens for /s/ and /z/ that were considered voiced or voiceless by the *duration.voiceless* measure. Generalised linear mixed-effects models were fitted with *duration.voiceless* as a dependent variable, and *speaker* and *word* as dependent variables. Likelihood ratio tests showed that neither the inclusion of *word.position* (χ^2 (2) = 5.58, p = .06) nor *segment* (χ^2 (1) = 1.75, p = .19) improved the fit of the model.

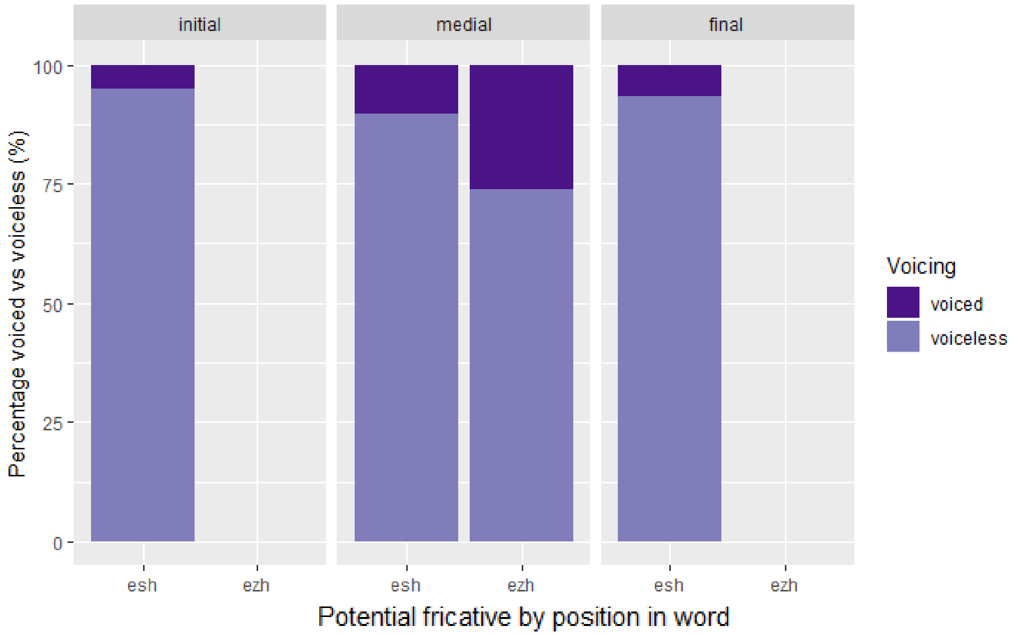
Figure 32 Percentage of potential alveolar fricatives voiced and voiceless according to duration voiceless measure



Postalveolar

Figure 33 below shows the percentage of tokens for each potential postalveolar fricative identified as voiced and voiceless by the *duration.voiced* measure. Taking just the word-medial potential postalveolar fricatives, generalised linear mixed-effects models were fitted with *duration.voiceless* as a dependent variable, and *speaker* and *word* as dependent variables. A likelihood ratio test showed that the inclusion of *segment* as a main effect provided a better fit than without (χ^2 (1) = 5.22, p = .022). The model showed that /ʒ/ is significantly more voiced than /ʃ/ by this measure (p = .028).

Figure 33 Percentage of potential postalveolar fricatives voiced and voiceless by position in word according to duration voiceless measure



Note: esh = /ʃ/, ezh = /ʒ/

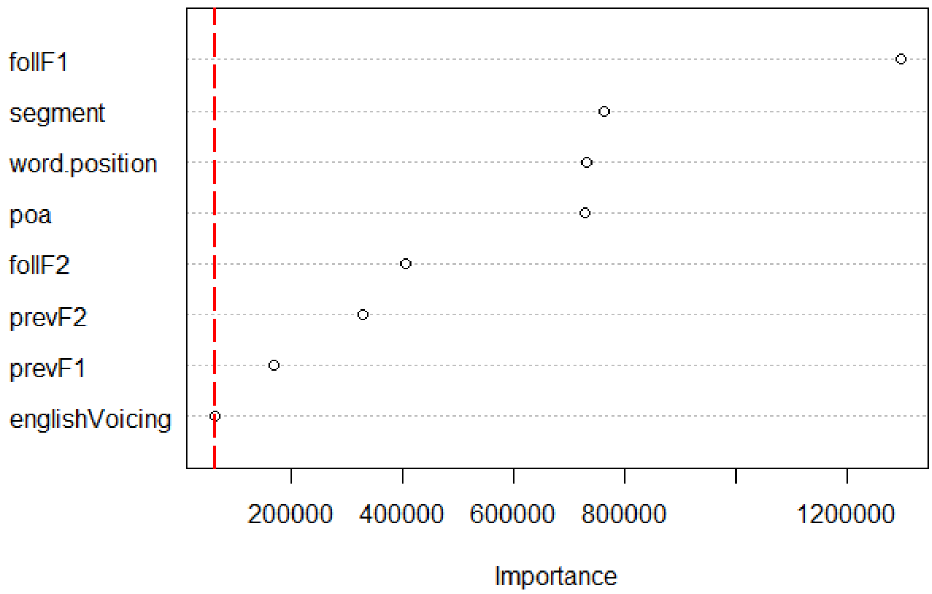
5.3.5 Mean frequency

A linear mixed-effects model with *mean* as a dependent variable, *segment* as a main effect, and *speaker* and *word* as random effects showed that the segment type was a significant predictor of the mean frequency of a fricative ($p < .001$). A post hoc analyses showed /v/ to have a lower mean than /s/ ($p < .001$) /z/ ($p = .013$) and /ʃ/ ($p = .003$). The mean of /f/ was also lower than that of /s/ ($p < .001$). No other contrasts reached significance.

A linear mixed-effects model with *mean* as a dependent variable, *POA* as a main effect, and *speaker* and *word* as random effects shows that place of articulation was a significant predictor of the mean frequency of a fricative ($p < .001$). A post hoc analysis showed labiodental fricatives to have lower mean frequencies than alveolar fricatives ($p < .001$) and postalveolar fricatives ($p < .01$). No other contrasts reached significance.

Figure 34 shows the variable importance ranking for *mean* as determined by a random forest analysis. The first formant of the following vowel was the most important variable influencing the mean frequency of the fricative. Next most important was the segment type, followed closely by the position in the word and the place of articulation. Whether or not the fricative is cognate with a voiced fricative in English was unimportant.

Figure 34 Variable importance for average frequency



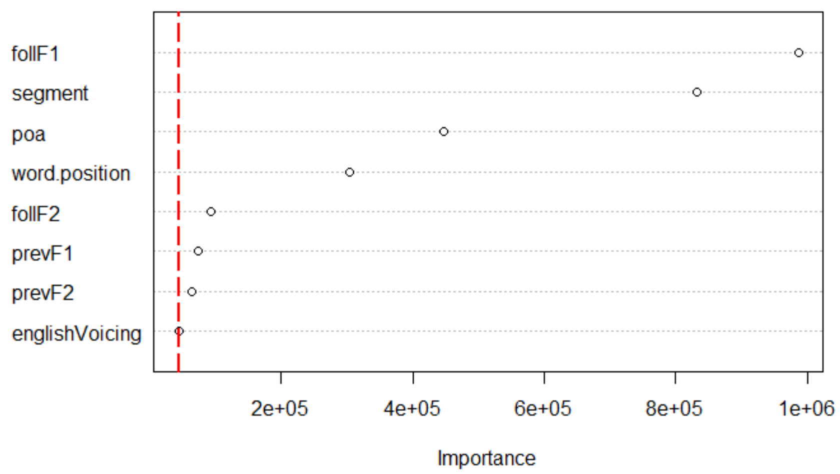
5.3.6 Standard Deviation

A linear mixed-effects model with *stdev* as a dependent variable, *segment* as a main effect, and *speaker* and *word* as random effects showed that the segment type was a significant predictor of the standard deviation of the frequency of a fricative ($p < .001$). A post hoc analysis showed potential /ʃ/ to have a significantly smaller standard deviation than both potential /f/ ($p < .01$) and /s/ ($p < .01$). Potential /v/ had a significantly smaller standard deviation than potential /f/ ($p = .018$) and potential /s/ ($p = .013$).

A linear mixed-effects model with *stdev* as a dependent variable, *POA* as a main effect, and *speaker* and *word* as random effects showed that place of articulation was a significant predictor of the standard deviation of the frequency of a fricative ($p = .016$). A post hoc analyses showed alveolar fricatives to have significantly greater standard deviations than postalveolar fricatives ($p = .018$). No other contrasts reached significance.

Figure 35 shows the variable importance ranking for *stdev* as determined by a random forest analysis. The first formant of the following vowel was the most important variable influencing the standard deviation of the fricative. Next most important was the segment type, followed by the place of articulation and position in the word. Whether or not the fricative is cognate with a voiced fricative in English was unimportant.

Figure 35 Variable importance for standard deviation



5.3.7 Skewness

Figure 36 shows the classification tree for the skewness. The first significant split in the data was by segment type (node 1, p <.001), with potential /v/ splitting off from all other potential fricatives. Potential /v/ had the highest skew values in the data. The second significant split was by place of articulation (node 3, p < .001), with potential alveolar and postalveolar fricatives splitting off from labiodental and dental fricatives – this is also a split between sibilants and non-sibilants respectively. The sibilants have lower skew values than the non-sibilants.

Within the non-sibilants, there was another significant split by fricative position in the word (node 4, p < .001). Final fricatives had higher skewness than initial and medial fricatives.

Within the sibilants, there was a significant split by whether the potential fricative would be voiced or voiceless in English (node 7, p < .001). Potential voiced sibilants had higher skewness than potential voiceless sibilants.

Figure 36 Classification tree for skewness

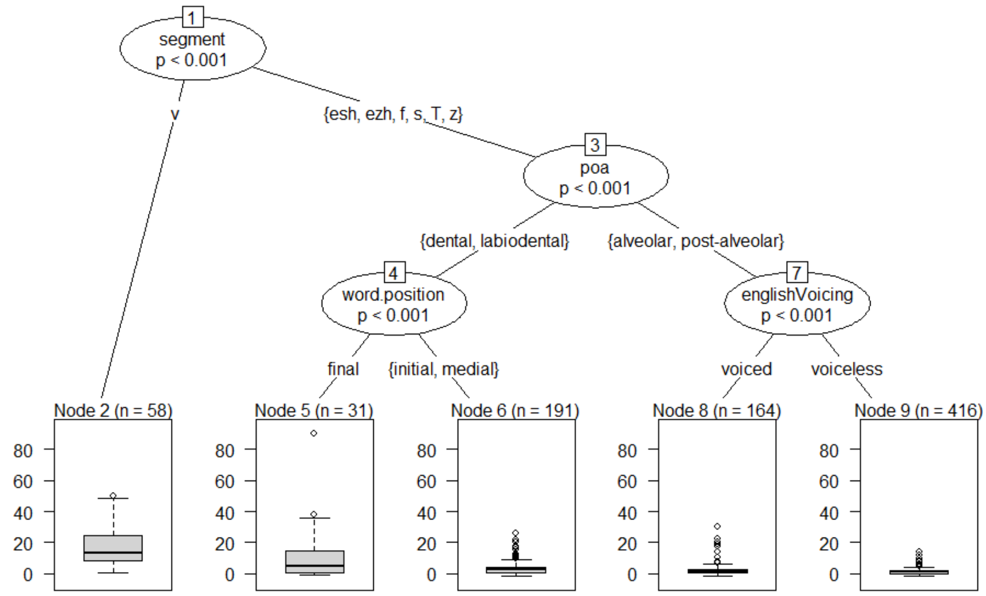
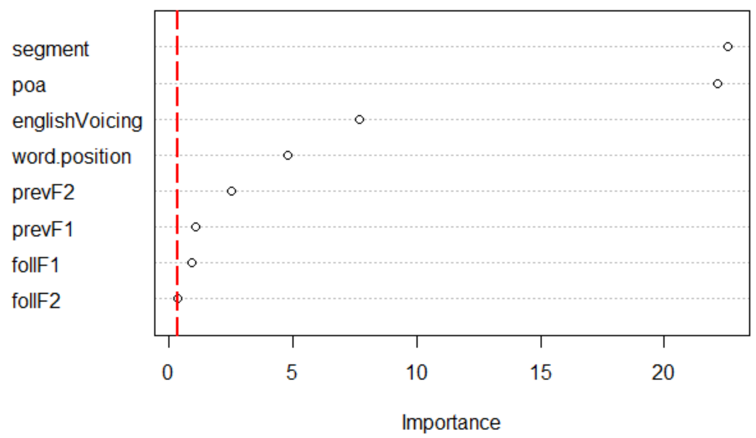


Figure 37 shows the variable importance ranking for *skew* as determined by a random forest analysis. The segment type and the place of articulation were the most important variables influencing the skewness of the fricative. Whether or not the fricative is cognate with a voiced fricative in English was next most important, followed by the position in the word.

Figure 37 Variable importance for skewness



5.3.8 Kurtosis

Figure 38 shows the classification tree for the kurtosis. It shows the same splits in the data as the skewness. The first significant split ($p < .001$) was by segment type (node 1), with potential /v/ splitting off from all other potential fricatives. Potential /v/ had the highest kurtosis values in the data. The second significant split was by place of articulation (node 3, $p < .001$), with potential alveolar and postalveolar fricatives splitting off from labiodental and dental fricatives. The sibilants (the potential alveolar and postalveolar fricatives) have lower kurtosis values than the non-sibilants.

Within the non-sibilants, there was another significant split by fricative position in the word (node 4, $p < .001$). Final fricatives had higher kurtosis than initial and medial fricatives.

Within the sibilants, there was a significant split by whether the potential fricative would be voiced or voiceless in English (node 7, $p = .004$). Potential voiced sibilants had higher kurtosis than potential voiceless sibilants.

Figure 38 Classification tree for kurtosis

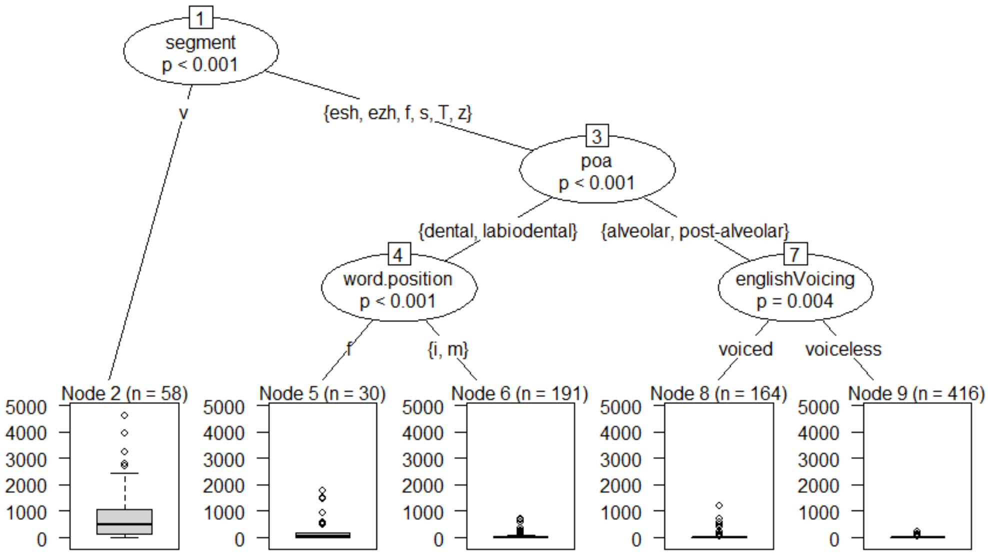
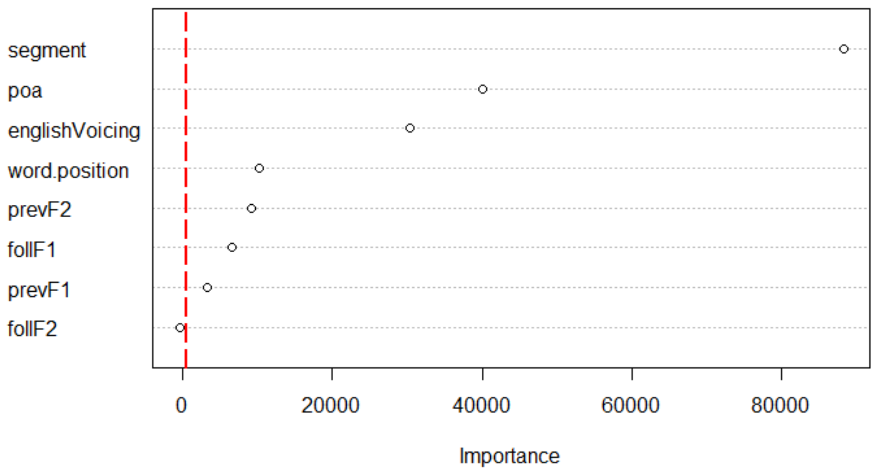


Figure 39 shows the variable importance ranking for kurtosis as determined by a random forest analysis. The segment type was the most important variable influencing the kurtosis of the fricative, followed by place of articulation. Whether or not the fricative was cognate with a voiced fricative in English was next most important, followed by the position in the word.

Figure 39 Variable importance for kurtosis



5.3.9 Normalised Intensity

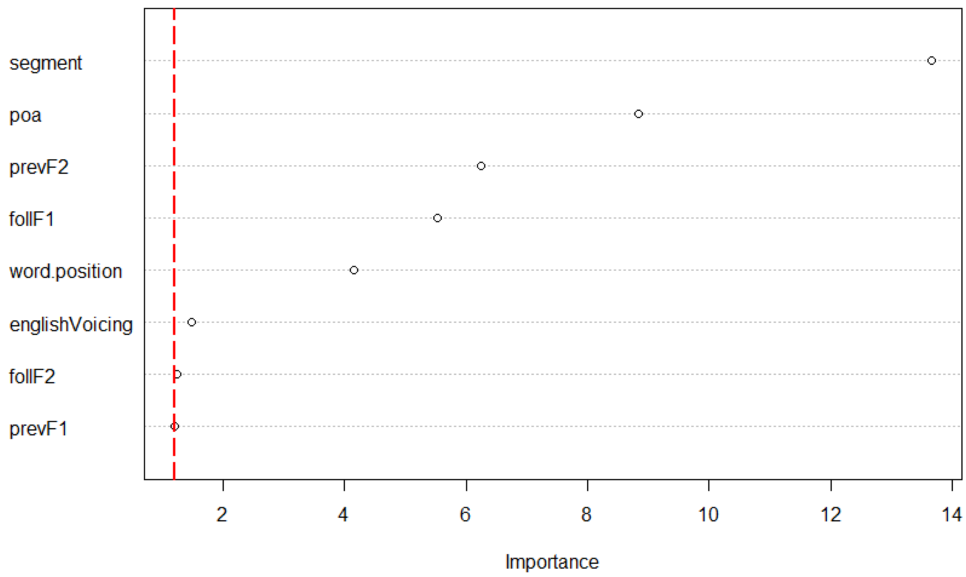
A linear mixed effects model with *norm.int* as a dependent variable, *segment* as a main effect, and *speaker* and *word* as random effects showed that the segment type was a significant predictor of the intensity of a fricative ($p < .001$). Post hoc analysis showed /f/ to have a lower normalised intensity than /θ/ ($p < .01$), /s/ ($p < .01$), /z/ ($p < .01$), and /ʃ/ ($p < .001$). Additionally, /ʃ/ had a higher normalised intensity than /v/ ($p < .001$), /s/ ($p < .001$) and /z/ ($p < .01$). No other contrasts reached significance.

A linear mixed-effects model with *norm.int* as a dependent variable, *POA* as a main effect, and *speaker* and *word* as random effects showed that place of articulation was a significant predictor of the normalised intensity of a fricative ($p < .001$). Post hoc analysis showed postalveolar fricatives to have significantly greater normalised intensity than alveolar fricatives ($p < .001$) and labiodental fricatives ($p < .001$). Labiodental fricatives also had significantly lower intensity than alveolar fricatives ($p < .01$) and dental fricatives ($p < .01$). The normalised intensity of dental fricatives did not contrast with alveolar or postalveolar fricatives.

Figure 40 shows the variable importance ranking for *norm.int* as determined by a random forest analysis. The segment type was the most important variable influencing the normalised intensity of the fricative, followed by place of articulation and the second formant of the previous vowel. Whether or not the fricative is cognate with a voiced fricative in

English was fairly unimportant, and ranked 6th among the independent variables.

Figure 40 Variable importance for normalised intensity



5.3.10 Data summary

Table 9 summarises the mean values and standard deviations for each variable by potential fricative. Table 10 shows a summary of the rankings provided by the random forest variable importance rankings for each independent variable and dependent variable. The independent variables are given in the rows, with the dependent variables in the columns. The lower the total in the rightmost column, the more important the independent variable across all independent variables.

Table 9 Average values for each variable

Potential fricative	Duration (ms)		Proportion voiced		Mean (Hz)		SD (Hz)		Skewness		Kurtosis		Normalised intensity (dB)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
/f/	128	42	0.42	0.34	2940	2660	2740	2150	4.5	8.5	118	699	-15.2	5.3
/v/	86	32	0.91	0.22	870	1880	1020	1860	17.6	13.0	901	1067	-12.1	5.8
/θ/	91	20	0.47	0.40	2690	1650	1830	910	4.4	6.9	92	187	-11.1	6.5
/s/	133	64	0.33	0.27	3930	1960	2520	1020	1.3	1.9	8	17	-11.7	6.1
/z/	118	48	0.44	0.35	3520	2120	2410	1160	2.4	4.5	39	137	-11.4	6.0
/ʃ/	145	43	0.24	0.20	3340	1020	1760	550	1.4	1.8	10	24	-7.5	5.8
/ʒ/	112	17	0.43	0.34	2610	790	1850	580	2.2	1.8	13	14	-11.3	3.8

Table 10 A summary of the variable importance rankings of the dependent variables for each dependent variable

	Duration	**Voicing**			**Spectral moments**				**Intensity**	
	Duration	Proportion Voiced	Duration voiced	Duration voiceless	Mean	SD	Skewness	Kurtosis	Normalised intensity	Total
segment	2	1	1	7	2	2	1	1	1	19
word.position	1	2	3	1	3	4	4	4	5	31
POA	6	3	2	8	4	3	2	2	2	35
follF1	8	4	4	5	1	1	7	6	4	42
englishVoicing	3	5	5	2	8	8	3	3	6	51
prevF2	4	6	6	6	6	6	5	5	3	54
foll F2	5	7	7	3	5	7	8	8	7	63
prevF1	7	8	8	4	7	5	6	7	8	65

It can thus be seen that ‘segment’ was ranked as the first or second most important predictor for every independent variable except the duration voiceless, for which it was ranked next to last. The table also shows that several of the dependent variables pair together. ‘Proportion voiceless’ and ‘duration voiced’ have the same variable importance rankings except for ranks two and three (word position and place of articulation), which are switched. Mean and standard deviation likewise have similar rankings, with ranks three and four (word position and place of articulation) switched and five and seven (following F2 and previous F1) switched. Skewness and kurtosis have only ranks six and seven (following F1 and previous F1) switched. Another match which might be expected does not appear: the variables rankings for ‘duration voiceless’ have little similarity to ‘proportion voiced’ and ‘duration voiced’.

5.4 Discussion

This section discusses the evidence for the discrimination of Light Warlpiri fricatives by place of articulation (§5.4.1), and voicing contrasts within these places of articulation (§5.4.2).

5.4.1 Place of articulation

Using the variables investigated, all four English places of articulation are distinguishable in Light Warlpiri.

Table 11 shows a summary of the measures that differed by each place of articulation contrast. The cell that aligns with the title 'labiodental' and the title 'dental' and reads 'normalised intensity' indicates that the normalised intensity was significantly different for labiodental and dental places of articulation. The cell below indicates that both mean and normalised intensity differed for potential labiodental fricatives compared with potential alveolar fricatives.

Table 11 Variables which differ significantly by place of articulation

Labiodental			
➢ Normalised intensity	**Dental**		
➢ Mean ➢ Normalised intensity	➢ Duration	**Alveolar**	
➢ Mean ➢ Normalised intensity	➢ Duration	➢ StDev ➢ Normalised intensity	**Postalveolar**

Normalised intensity was significantly different for labiodental, alveolar, and postalveolar places of articulation, but did not distinguish dental fricatives. The mean frequency was significantly different for labiodental fricatives compared with both alveolar and postalveolar fricatives. The standard deviation was significantly different for potential alveolar compared with potential postalveolar fricatives. Duration was the only variable that differed significantly for dental fricatives compared with alveolar and postalveolar fricatives. Potential labiodental, alveolar, and postalveolar fricatives were thus differentiated from each other by several measures, whereas dental fricatives were distinguished from these by only one measure each. That labiodental, alveolar, and postalveolar fricatives should be better discriminated than dental fricatives is unsurprising if the latter are only allophones of a stop consonant, as proposed in section 4.3.2.

5.4.2 Voicing distinctions

The potential voicing pairs in Light Warlpiri are /f-v/, /s-z/, and /ʃ-ʒ/, given that /θ/and /ð/ appear not to be phonological fricatives (§4.3.2). A summary of how these pairs differ is given in Table 12. Since classification trees cannot take random variables such as speaker and word into account as linear mixed-effects models can, the presence of a significant split in a classification tree should not be given as much credence as in a linear mixed effect model.

Table 12 Variables by which potential voiceless-voiced pairs do or do not differ

Potential voiceless/voiced pair	Duration	Proportion Voiced	Duration voiced	Duration voiceless	Mean	StDev	Skew (no lmer available)	Kurtosis (no lmer available)	Normalised intensity
/f-v/	✓	✓	✓	×	C-tree only	✓	✓	✓	C-tree only
/s-z/	C-tree only	C-tree only	×	×	×	×	✓	✓	×
/ʃ-ʒ/	×	×	×	✓	×	C-tree only, when following vowel is a low vowel	✓	✓	C-tree only

Given this, the only potential voicing pair that was consistently distinguished in Light Warlpiri was potential /f/ and /v/. They were distinguished by mixed-effects models for *proportion voiced* and *duration voiced*, as well as *duration,* a secondary cue to voicing. Furthermore, these distinctions are in the direction expected: potential /v/ has a higher proportion of voicing than potential /f/, and its duration is shorter. Although they are not differentiated by *duration.voiceless*, the theory behind this measure is based on English speaker perception, as opposed to the production. It may be that Light Warlpiri speakers perceive the voicing of a fricative differently from English speakers, yet distinguish them similarly in terms of production. Alternatively, there may be an acoustic difference but no perceptual difference.

The table shows evidence against a voicing distinction in the potential /s-z/ and /ʃ-ʒ/ pairs. Linear mixed-effects models showed no significant differences between potential /s/ and /z/ for any of the voicing measures or duration. The model for *duration.voiceless* did show a significant difference between /ʃ/ and /ʒ/, with /ʒ/ more likely to be voiced. However, given its perceptual basis, as just discussed, and the fact that the pair was not significantly differentiated in any of the other measures of voicing, I do not take this to be good evidence of a distinction. The phoneme /ʒ/ is one of the least common phonemes in English (Hayden, 1950; Mines, Hanson, & Shoup, 1978). The only word in the dataset containing /ʒ/ was ‘Casuarina’, as in ‘Casuarina Square’, the proper name of a major shopping centre in the Northern Territory. It is unlikely that enough tokens of potential /ʒ/ have entered Light Warlpiri for there to be enough impetus to differentiate them from potential /ʃ/. For these reasons, I conclude that there is a voicing distinction for labiodental fricatives /f-v/ in Light Warlpiri, but not for alveolar or postalveolar fricatives.

Chapter 6: General discussion

This discussion chapter begins with a summary of the findings from the two studies and a proposal for a Light Warlpiri fricative inventory (§6.1). Then, cross-linguistic comparisons with Kriol, Gurindji Kriol, and varieties of English are made (§6.2), including a comparison of the acoustic properties of Light Warlpiri fricatives with the trends found in English (§6.2.1). Implications for mixed language research are briefly discussed in section 6.2.2. Finally, the limitations of this thesis and some suggestions for future research are provided (§6.3).

6.1 Proposed fricative inventory for Light Warlpiri

To remind the reader, the questions under investigation in this thesis are:

1. Are the reflexes of English fricatives produced as fricatives in Light Warlpiri?
2. If they are, are the fricatives from one place of articulation in English distinct from those from another place of articulation?
3. Are English-like fricative voicing distinctions maintained in Light Warlpiri?

The first of these questions was answered in Chapter 4. Most of the reflexes of English fricatives are indeed produced as fricatives in Light Warlpiri. The exceptions to this are /h/, which is deleted, and the potential dental fricatives, which are stops, though some speakers also produced a word-final fricative allophone of potential /θ/. Whilst many tokens of potential /f/ and /v/ were produced as stops, both stops and fricatives were found in all word positions. Coupling this with the perceptual findings from Bundgaard-Nielsen, O'Shannessy, and Baker (2015), I concluded that /f/ and /v/ are fricatives, distinct from the stop series. The overwhelming majority of sibilants were found to be fricatives.

Questions two and three were answered in Chapter 5. The acoustic properties under investigation distinguished between all English places of articulation, with normalised intensity being the best discriminant. Voicing was contrastive only between the potential labiodental fricatives /f/ and /v/.

Thus, based on the results and discussions from Chapters 4 and 5, I propose the following fricative inventory for Light Warlpiri:

Table 13 Proposed fricative inventory for Light Warlpiri

Labiodental	Alveolar	Postalveolar
f v	s	ʃ

The reflexes of English fricatives in Light Warlpiri are as follows:

1. /f/ remains /f/
2. /v/ remains /v/
3. /ð/ becomes a stop
4. /θ/ becomes a stop with fricative allophones word-finally for some speakers
5. /s/ and /z/ become /s/
6. /ʃ/ and /ʒ/ become /ʃ/
7. /h/ is deleted

In their acoustic study of Light Warlpiri stops, Bundgaard-Nielsen and O'Shannessy (2019) found no voice onset time distinction between word-initial reflexes of /ð/ and /θ/. This suggests that these reflexes have merged; however, without being able to compare how they behave word-finally, I have decided to keep them separate in the list above.

It is important to note that even though Light Warlpiri fricatives show distinctions by the place of articulation of their English sources, it does not mean that the places of articulation are actually the same as those of English. Baker, Bundgaard-Nielsen and Graetzer (2014), for example, suggest that Kriol reflexes of /f/ are actually produced as [ɸ]. Articulatory studies would need to be conducted to confirm where the places of articulation of Light Warlpiri fricatives indeed are.

It may also be the case that /v/ is not a genuine fricative. The experienced phonetician who provided manner of articulation judgements for the first study judged most of the instances of potential /v/ to be approximants or lightly-fricated approximants, rather than actual fricatives. Furthermore, /v/ differed significantly from all other potential fricatives in that it had a lower mean frequency and much higher skewness, indicating the clustering of energy in the lower frequencies. This could be due to a lack of high-frequency turbulence.

Given the degree of articulatory precision required in the production of fricatives (Ladefoged & Maddieson, 1996), and the added challenge of keeping the cross-sectional areas of the supra-glottal and glottal constrictions in voiced fricatives approximately equal (Stevens et al., 1992, p. 1980-81), it would be unsurprising for Light Warlpiri /v/ to be produced as an approximant. Indeed, Martínez-Celdrán (2004) proposes the following definition of the term 'approximant', which gives a sense of their relation to fricatives:

> Approximants are segments that, having a certain degree of constriction, lack a turbulent airstream, either due to the non-existence of the necessary articulatory precision required to produce it, or because the vocal tract is not narrow enough, or because both these conditions occur simultaneously (p. 207).

Additionally, /v/ being an approximant could account for why there is no difference in normalised intensity between /f/ and /v/. In English, voiced fricatives have lower intensities than their voiceless counterparts (see section 6.2.1 below). Cross-linguistically, though, sonorants generally have greater intensities than obstruents (Jany, Gordon, Nash, & Takara, 2007). So, if /v/ is customarily produced as an approximant, the increased sonorance and thus intensity may be cancelling out this voiced-voiceless intensity distinction.

Whether the target of potential /v/ in Light Warlpiri is a fricative, with less precise articulation resulting in its production as an approximant, or whether the target is actually an approximant, remains to be seen.

6.2 Cross-linguistic comparisons

The proposed fricative inventory in the section above does not exactly match that of any of the Light Warlpiri adstrates. In this section, I compare some of the key features of the proposed inventory with the English-related Light Warlpiri source languages – Aboriginal English, Standard Australian English, and Kriol – as well as the mixed language Gurindji Kriol.

That Light Warlpiri has undergone /h/-deletion is cross-linguistically unsurprising. Buchan's (2012) investigation of Standard Australian English in Katherine, Northern Territory, found that rates of /h/-deletion ranged from 14.00% to 39.23%, with total percentage deletion across participants at 28.28%. In Australian Aboriginal English, /h/ is commonly deleted, even in acrolectal varieties (Butcher, 2008). Although the obstruent inventory of Roper River Kriol contains /h/ (Baker et al., 2014), it was initially omitted in the early days of Kriol (Sandefur, 1979). It was not until the levelling processes due to sustained contact with English took effect that word-initial /h/ was reintroduced into the language (Sandefur, 1979; Sharpe & Sandefur, 1976). It is not clear how frequently reflexes of English /h/ are absent in Kriol at present. For Gurindji Kriol, Buchan (2012) reports that just 0.02% of potential /h/'s were actually judged to be produced with [h] by transcribers (p. 92). Thus, /h/-deletion is common in the Aboriginal English and Kriol source languages of Light Warlpiri, as well as a neighbouring mixed language with a similar typology.

It is also not surprising for Light Warlpiri dental fricatives to be produced as stops. The reflexes of dental fricatives are stops in both Aboriginal English (Butcher, 2008) and Kriol (Baker et al., 2014). The Kriol obstruent inventory developed by Baker et al. (2014), does not contain dental fricatives. The majority of potential dental fricatives in Gurindji Kriol were also produced as stops in Buchan's study (2012).

The lack of a voicing distinction in the alveolar and postalveolar fricatives can be anticipated from the Light Warlpiri adstrates. Both Kriol and Aboriginal English lack contrastive voicing in their fricative series (Baker et al., 2014; Butcher, 2008). A difference in voicing between /f/ and /v/, however, is unexpected – both because of the lack of voicing contrasts in Kriol and Aboriginal English, and because the reflexes of /v/ in these languages are stops. Butcher (2008) reports that reflexes of labiodental fricatives become bilabial stops in Aboriginal English, and makes no mention of a difference in treatment between /f/ and /v/. Sandefur (1979) wrote that the reflex of English /f/ in Kriol was historically [ɟ], but thanks to levelling effects over time this changed to /f/, so that /f/ is in now part of the Kriol obstruent inventory (Baker et al., 2014). However, the reflex of English /v/ – both historically and presently – is Kriol /b/ (Baker et al., 2014; Sandefur, 1979). There is thus precedent for the reflexes of /f/ and /v/ to differ, but it would be more expected for /v/ to become /b/ rather than to remain as a fricative (or approximant, as the case may be). Why a voicing distinction should be found only in labiodental fricatives is not entirely clear; however, it shows that Standard Australian English has had a substantial influence on Light Warlpiri.

This influence from Standard Australian English is one respect in which Light Warlpiri differs from Gurindji Kriol, and may account for why a far smaller proportion of potential fricatives in Light Warlpiri are produced as stops. Table 14 shows the percentage of potential fricatives in Gurindji Kriol and Light Warlpiri that were produced as stops, referring to Buchan (2012, p. 104-6) for the Gurindji Kriol data. (Tokens that were not produced as stops were produced as either fricatives, affricates, approximants, or not at all.) Except for the potential dental fricatives, all were realised as stops substantially more often in Gurindji Kriol compared with Light Warlpiri – particularly the sibilants. Of course, the methodology used in this thesis differs substantially from that used by Buchan, so the comparison should not be given too much weight. However, the greater percentage of stop realisations in Gurindji Kriol suggests a stronger influence from traditional Australian language phonologies compared with Light Warlpiri. Sandefur's (1979) historical description of the L2 acquisition of English-derived fricatives by L1 speakers of traditional Australian languages shows that these speakers systematically replaced fricatives with stops (p. 37). Another way of interpreting this is that the Standard Australian English phonology has had a greater influence on Light Warlpiri than on Gurindji Kriol. Implications of this for mixed language research are discussed in section 6.2.2.

Table 14 Comparison of stop production of potential fricatives in Gurindji Kriol and Light Warlpiri

Potential fricative	**Percentage produced as stops** Gurindji Kriol (Buchan, 2012, p. 104-6)	 Light Warlpiri
/f/	58%	12%
/v/	77%	51%
/θ/	87%	76%
/ð/	84%	100%
/s/	52%	0.8%
/z/	No data	0%
/ʃ/	69%	0%
/ʒ/	No data	0%

6.2.1 Acoustic comparison with English

The patterns found in the literature on the acoustic properties of English fricatives (§2.1) are summarised in Table 15 below. A tick in the rightmost column indicates that Light Warlpiri follows the same pattern as English (with caveats in parentheses), whereas a cross indicates that it does not.

Table 15 Comparison of Light Warlpiri with acoustic patterns in English

	Pattern	**References**	**In Light Warlpiri?**
Duration	Phonologically voiceless fricatives are longer than their voiced counterparts	Baum & Blumstein, 1987; Crystal & House, 1988; Silbert & de Jong, 2008	✓ (potential /f/ compared with potential /v/ only)
	Non-sibilants have a shorter duration than voiced sibilants	Behrens & Blumstein, 1988; Jongman et al., 2000	✗
Spectral values	Mean frequency of /s/ higher than /ʃ/	Jongman et al., 2000; Nissen & Fox, 2005; Nittrouer, 1995; Nittrouer et al., 1989; Onaka & Watson, 2000	✓ (but non-significant)

	Variance of non-sibilants higher than for sibilants	Jongman et al., 2000; Nissen & Fox, 2005; Onaka & Watson, 2000	×
	Postalveolar fricatives have the highest values for skewness	Jongman et al., 2000; Nissen & Fox, 2005; Nittrouer, 1995; Onaka & Watson, 2000	×
Amplitude/ intensity	Voiceless fricatives have greater amplitudes than their voiced counterparts	Jongman et al., 2000; Silbert & de Jong, 2008	×
	Non-sibilants have lower amplitudes than sibilants	Jongman et al., 2000; Nissen & Fox, 2005	×
	As the place of articulation moves from front to back, the normalised amplitude increases	Jongman et al., 2000; Nissen & Fox, 2005	✓

Duration

Whilst phonologically voiceless fricatives in English are longer in duration than phonologically voiced fricatives (Baum & Blumstein, 1987; Crystal & House, 1988; Silbert & de Jong, 2008), only the /f-v/ pair follows this pattern in Light Warlpiri. I have cited it as evidence of a labiodental voicing split (§5.4.2).

Non-sibilants in English are generally shorter than sibilants in English (Behrens & Blumstein, 1988; Jongman et al., 2000), but this trend is not maintained in Light Warlpiri. Potential /v/ was significantly shorter than potential /s/ and /ʃ/, but it was also significantly shorter than /f/, with no other contrast reaching significance.

Spectral moments

The trend for English that potential /s/ has a higher mean frequency than potential /ʃ/ (Jongman et al., 2000; Nissen & Fox, 2005; Nittrouer, 1995; Nittrouer et al., 1989; Onaka & Watson, 2000) was maintained in Light Warlpiri. However, the difference was not significant. When /s-z/ and /ʃ-ʒ/ pairs were each combined, alveolar fricatives had higher mean frequencies than postalveolar fricatives, but the difference remained non-significant.

The split in variance between sibilants and non-sibilants in English was not maintained in Light Warlpiri. Though Nissen and Fox (2005), Jongman et al. (2000), and Onaka and Watson (2000) reported higher variance for non-sibilants than for sibilants, the standard deviations of both non-sibilant /v/ and sibilant /ʃ/ were significantly lower than those of non-sibilant /f/ and sibilant /s/ in Light Warlpiri. Thus, there was no distinction according to sibilance.

Though postalveolar fricatives are found to have the highest skewness values of the English fricatives (Jongman et al., 2000; Nissen & Fox, 2005; Nittrouer, 1995; Onaka & Watson, 2000), this is clearly not the case in Light Warlpiri. Voiceless sibilants actually had the lowest skewness values, indicating a concentration of energy in the upper frequencies. Potential /v/ had the highest skewness values by far, which I have noted may indicate its production as an approximant rather than as a fricative.

Amplitude/intensity

The English trend that voiceless fricatives have greater amplitude than their voiced counterparts (Jongman et al., 2000; Silbert & de Jong, 2008) was not maintained in Light Warlpiri. There were no significant contrasts within a potential voiced-voiceless pair for any place of articulation, including /f-v/.

A split in amplitude between sibilants and non-sibilants as reported by Jongman et al. (2000) and Nissen and Fox (2005) also was not maintained. Potential /ʃ/ had higher intensity than /v, f, s/, and /z/, and potential /f/ had less intensity than /θ, s, z/ and /ʃ/, but there were no significant differences between /θ, v, s, z/ and /ʒ/. When considered by place of articulation, labiodental fricatives do have significantly lower normalised intensity than alveolar and postalveolar fricatives, but dental fricatives do not differ significantly.

For the three places of articulation that do differ by normalised intensity, a trend found in English is maintained: the further back in the oral cavity the place of articulation, the greater the normalised intensity (Jongman et al., 2000; Nissen & Fox, 2005).

Analysis

What this comparison shows is that, in general, Light Warlpiri does not have the same kind of sibilant versus non-sibilant distinction that is found in English. The only clear distinction between sibilants and non-sibilants is in the classification trees for skewness and kurtosis. Sibilants are sibilants because of their large amounts of acoustic energy concentrated at high frequencies (Ladefoged, 1971, p. 57). The low skewness values for the potential sibilants in Light Warlpiri compared with the potential non-sibilants shows that this distinction is maintained. However, other characteristics that distinguish sibilants from non-sibilants in English such as greater intensity, variance, and length are not.

Secondary cues to voicing distinctions in English such as the increased duration and normalised intensity of voiceless fricatives are also not maintained in Light Warlpiri. The exception to this is that /f/ is significantly longer than /v/. An explanation for a lack of difference in normalised intensity for /f/ and /v/ has been posited in section 6.1. However, no explanation is forthcoming for the other voiced/voiceless pairs, other than the argument already presented that there is no voicing distinction for alveolar and postalveolar fricatives in Light Warlpiri.

6.2.2 Implications for mixed language research

Though it is difficult to quantify influence, the incorporation of a voicing contrast that is not typical of Kriol or Aboriginal English shows that Standard Australian English has contributed substantially to the Light Warlpiri sound system. This presents evidence against Rosen et al.'s (2019) suggestion that ancestral languages play a larger role in mixed language grammars than introduced languages. Since this thesis, by design, excludes the analysis of words with Warlpiri sources, no comment can be made about the possibility of source-based stratification. However, these findings provide further support for the argument that the ways in which source languages combine in the phonologies of mixed languages are more complex than simple wholesale transference or assimilation.

6.3 Limitations and suggestions for future research

The biggest limitation to this thesis is that there were no men included in this dataset, which was due to cultural constraints. Since the acoustic properties of fricatives have been shown to differ by gender in English (Fox & Nissen, 2005; Jongman et al., 2000; Koenig et al., 2013; Li et al., 2016; Silbert & de Jong, 2008), it is necessary to conduct an analysis of fricatives produced by Light Warlpiri-speaking men before we can have a full understanding of the acoustic properties of the fricatives. Additionally, the sociolinguistic backgrounds of the speakers have been largely ignored, due to the prioritisation in this thesis of the properties common across speakers. More detailed investigations of the interactions between social factors and fricative production could illuminate, for example, the conditions under which a potential labiodental fricative is produced as a stop rather than a fricative. The level of a participant's familiarity with English was found to have a slight effect in Gurindji Kriol perception studies (Stewart et al., to appear, 2018), and it may be that such an effect can also be found in Light Warlpiri.

This thesis also lacked data from fricatives in several word positions. There was no word-initial potential /v/, no non-word-initial /ð/, only one word containing word-initial /z/, and /ʒ/ appeared only word-medially. It may be the case that these potential fricatives are not found in these positions in Light Warlpiri, but if they are then they should be investigated in future studies.

It should also be kept in mind that this thesis looks only at words with potential fricatives. It thus provides no comment on fricatives in Light Warlpiri that appear in places that would be unexpected based on English. For example, several potential stops and affricates that were encountered incidentally in the data, such as the /p/ in 'swimming pool' and the /tʃ/ in 'chair', appeared to be produced as fricatives or lightly-fricated approximants. Likewise, this thesis cannot rule out the possibility of the presence of /h/ through /h/-insertion. Butcher (2008) reports that h-insertion is a frequent occurrence in Aboriginal English (p. 629), so it is possible that, contrary to the data shown here, /h/ is frequently used in Light Warlpiri. Additional insight into Light Warlpiri fricatives might therefore be gained from analysing fricatives that occur in words with no 'potential' fricatives.

There were several acoustic measures that could have been used but which were beyond the scope of this thesis. Other possible measures include the spectral slope, the spectral peak, transitions, fricative-vowel coarticulation effects, and dynamic measures that show how the acoustic properties of the fricatives change from the start to the end of their production. There was also no inclusion of the effect of word stress in this thesis, since not enough is yet known about Light Warlpiri stress. These measures present potential avenues for further acoustic work on Light Warlpiri fricatives.

One of the disadvantages of using a spectral moment analysis is that the relationship between physical articulation and the acoustic properties is not straight forward (Koenig et al., 2013, p. 1177). Similarly, factors that appear important acoustically may or may not be important to perception. It would thus be beneficial to conduct both articulatory and further perceptual studies on Light Warlpiri fricatives in order to get a fuller picture.

Finally, it is likely the case that Light Warlpiri, as a relatively young language, is still in the process of developing and conventionalising contrasts. It may be, for example, that an alveolar voicing distinction is emerging; discrimination of /s/ and /z/ in the perception study was better than chance, after all (Bundgaard-Nielsen et al., 2015). It would be very interesting for a follow-up study to be performed in ten years' time to see how fricatives in the language have changed.

Chapter 7: Conclusion

To summarise the findings of this thesis, the first study (Chapter 4) presented an analysis of the stop-fricative variation in Light Warlpiri. It was shown that there is widespread /h/-deletion, and dental fricatives are produced as stops. English labiodental, alveolar, and postalveolar fricatives were shown to be fricatives in Light Warlpiri.

The second study (Chapter 5) presented an acoustic analysis of Light Warlpiri fricatives. The properties under investigation successfully discriminated along all English place of articulation divisions, with normalised duration being the best discriminant. There was shown to be a voicing distinction between /f/ and /v/, and evidence was presented that showed /v/ may customarily be produced as an approximant rather than a true fricative. There was shown to be no contrastive voicing for alveolar or postalveolar fricatives.

Based on the evidence from these two studies, I proposed a fricative inventory of Light Warlpiri consisting of /f, v, s/ and /ʃ/. This differs from all source languages, providing support for the argument that source-language influence on the phonologies of mixed languages is complex.

This thesis presents a comprehensive analysis of Light Warlpiri fricatives and a strong starting point from which future acoustic, articulatory, and perceptual work can be carried out. It also has potential applications in language acquisition research, as it provides information on the targets for L1 acquisition of Light Warlpiri. These findings also suggest that Light

Warlpiri-speaking children may require explicit instruction on the production of /h, θ/, and /ð/, and the voicing distinctions between /s-z/ and /ʃ-ʒ/ for the purposes of acquiring and learning in Standard Australian English. Finally, this thesis provides a snapshot of the fricative inventory of Light Warlpiri as it is approximately 40 years after its genesis. It is hoped that this will be used as a point of comparison for research on how the language changes in the future.

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Appendix A: Words

Word	Potential fricative	Position in word	Asterisk indicates just one token
ash	ʃ	Final	
baptise	z	Final	
baptising	z	Medial	
Sleep	s	Initial	
sleeping	s	Initial	
birthday	θ	Medial	*
brush	ʃ	Final	
buffalo	f	Medial	
bush	ʃ	Final	*
butterfly	f	Medial	
Casuarina Square	ʒ	Medial	
Casuarina Square	s	Medial	
cave	v	Final	
cemetery	s	Initial	
centre	s	Initial	*
cents	s	Initial	*
cents	s	Final	*
cereal	s	Initial	
cheese	z	Final	
clothes	ð	Medial	
clothes	z	Final	
coffee	f	Medial	
coffin	f	Medial	
cough	f	Final	
coughing	f	Medial	
cover	v	Medial	
covering	v	Medial	
cross	s	Final	
dancing	s	Medial	
dress	s	Final	*
driver	v	Medial	*
driving	v	Medial	
face	s	Final	*
faldaning	f	Initial	
fall	f	Initial	*
falldown	f	Initial	*
family	f	Initial	

fat	f	Initial	
fatwan	f	Initial	
fence	f	Initial	
fence	s	Final	
fighting	f	Initial	*
finding	f	Initial	
fire	f	Initial	
fish	f	Initial	
fish	ʃ	Final	
fixing	f	Initial	
fixing	s	Medial	
fly	f	Initial	*
flyingfox	f	Initial	
flyingfox	f	Medial	
flyingfox	s	Final	
footpath	f	Initial	
footpath	θ	Final	
four	f	Initial	
fridge	f	Initial	
gift	f	Medial	*
giraffe	f	Final	*
giving	v	Medial	
glove	v	Final	*
graveyard	v	Medial	
happy	h	Initial	
having	h	Initial	*
fun	f	Initial	*
frog (brogbrog)	f	Initial	
pussycat (pujiket)	s	Medial	
horse	h	Initial	
horse	s	Final	
hose	h	Initial	
hose	z	Final	
house	h	Initial	*
house	s	Final	*
insect	s	Medial	
his	h	Initial	*
his	z	Final	*
laughing	f	Medial	
knife	f	Final	
lips	s	Final	
stick	s	Initial	*
matches	z	Final	

mattress	s	Final	
mess	s	Final	
moth	θ	Final	
needles	z	Final	*
noodles	z	Final	*
nose	z	Final	
outside	s	Medial	*
ox	s	Final	
box	s	Final	
phone	f	Initial	
telephone	f	Medial	
pushing	ʃ	Medial	
rifle	f	Medial	*
river	v	Medial	
sad	s	Initial	
salt	s	Initial	
school	s	Initial	*
scissors	s	Initial	
scissors	z	Medial	
scissors	z	Final	
scratch	s	Initial	
sea	s	Initial	
shangayi	ʃ	Initial	*
shed	ʃ	Initial	*
shell	ʃ	Initial	
shirt	ʃ	Initial	
shop	ʃ	Initial	
shopping	ʃ	Initial	*
shouting	ʃ	Initial	*
shovel	ʃ	Initial	
shovel	v	Medial	
sign	s	Initial	*
singing	s	Initial	
sitting	s	Initial	
slip	s	Initial	
stairs	s	Initial	
stairs	z	Final	
snake	s	Initial	*
soap	s	Initial	
soup	s	Initial	
spilling	s	Initial	*
standing	s	Initial	
standupping	s	Initial	*

steak	s	Initial	
sticking	s	Initial	*
stone	s	Initial	
storing	s	Initial	*
sugar	ʃ	Initial	
sun	s	Initial	
swimming(pool)	s	Initial	
swing (swingswing)	s	Initial	
Sydney Harbour Bridge	s	Initial	
Sydney Harbour Bridge	h	Medial	
the	ð	Initial	
they're	ð	Initial	
thinking	θ	Initial	
thirsty	θ	Initial	
thirsty	s	Medial	
this	ð	Initial	
this	s	Final	
thong	θ	Initial	
thongs	θ	Initial	
thongs	z	Final	
throat	θ	Initial	*
washing	ʃ	Medial	
whistle	s	Medial	
zebra	z	Initial	*
zoo	z	Initial	

Appendix B: Mixed-effects model outputs

8.1 Duration

8.1.1 General

Formula: duration ~ segment + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
segment	0.057427	0.0095711	6	92.495	6.289	1.43E-05	***

p < .05 (*); p < .01 (**); p < .001 (***)

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	0.140678	0.010003	13.810381	14.063	1.42E-09	***
segmentezh	-0.017773	0.018416	38.433108	-0.965	0.34054	
segmentf	-0.006932	0.006294	110.234806	-1.101	0.2731	
segments	-0.001084	0.006454	97.530524	-0.168	0.86693	
segmentT	-0.037319	0.012559	323.269757	-2.972	0.00318	**
segmentv	-0.040476	0.008594	144.824167	-4.71	5.75E-06	***
segmentz	-0.020077	0.007158	91.109912	-2.805	0.00615	**

p < .05 (*); p < .01 (**); p < .001 (***)

Estimated marginal means

contrast	estimate	SE	df	t.ratio	p.value	
esh-ezh	0.01777	0.01843	37.5	0.964	0.9586	
esh-f	0.00693	0.00637	107.8	1.088	0.9303	
esh-s	0.00108	0.00652	95.3	0.166	1	
esh-T	0.03732	0.01265	317.8	2.951	0.0523	
esh-v	0.04048	0.00869	141.7	4.657	0.0001	***
esh-z	0.02008	0.00724	89	2.773	0.0928	
ezh-f	-0.01084	0.01845	37.4	-0.588	0.9968	
ezh-s	-0.01669	0.0184	37.7	-0.907	0.9692	
ezh-T	0.01955	0.02139	59.2	0.914	0.9689	
ezh-v	0.0227	0.01952	41.4	1.163	0.9038	
ezh-z	0.0023	0.01868	38.2	0.123	1	
f-s	-0.00585	0.0067	82.5	-0.873	0.9756	
f-T	0.03039	0.01191	514.1	2.552	0.1432	
f-v	0.03354	0.00928	101.4	3.614	0.0083	**
f-z	0.01315	0.00743	79.3	1.769	0.5727	
s-T	0.03623	0.01269	294.9	2.855	0.0683	
s-v	0.03939	0.00925	103.4	4.26	0.0009	***
s-z	0.01899	0.0065	178.5	2.923	0.0588	
T-v	0.00316	0.01432	242.9	0.22	1	
T-z	-0.01724	0.01307	264.3	-1.319	0.8426	
v-z	-0.0204	0.00976	97.5	-2.089	0.3673	

p < .05 (*); p < .01 (**); p < .001 (***)

Formula: duration ~ poa + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
poa	0.019394	0.0064646	3	151.13	4.2101	0.006823	**

p < .05 (*); p < .01 (**); p < .001 (***)

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	0.133088	0.009981	12.67692	13.334	7.86E-09	***
poadental	-0.033624	0.012825	340.5424	-2.622	0.00914	**
poalabiodental	-0.008129	0.006191	84.593195	-1.313	0.19269	
poapostalveolar	0.007239	0.006342	96.803215	1.142	0.25646	

p < .05 (*); p < .01 (**); p < .001 (***)

Estimated marginal means

contrast	estimate	SE	df	t.ratio	p.value	
alveolar-dental	0.03362	0.01289	327.3	2.608	0.0468	*
alveolar-labiodental	0.00813	0.00624	79.8	1.304	0.5633	
alveolar-postalveolar	-0.00724	0.0064	91.5	-1.131	0.6711	
dental-labiodental	-0.02549	0.01218	552.4	-2.092	0.1568	
dental-postalveolar	-0.04086	0.01298	389	-3.148	0.0095	**
labiodental-postalveolar	-0.01537	0.00601	162.3	-2.558	0.0551	

p < .05 (*); p < .01 (**); p < .001 (***)

8.1.2 Labiodental

Formula: duration ~ segment + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
segment	0.014005	0.014005	1	18.948	13.945	0.001411	**

p < .05 (*); p < .01 (**); p < .001 (***)

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	0.132584	0.009016	15.449758	14.705	1.70E-10	***
segmentv	-0.039649	0.010618	18.947658	-3.734	0.00141	**

p < .05 (*); p < .01 (**); p < .001 (***)

Estimated marginal means

contrast	Estimate	SE	df	t.ratio	p.value	
f-v	0.0396	0.0107	20.4	3.702	0.0014	**

p < .05 (*); p < .01 (**); p < .001 (***)

8.1.3 Alveolar

Formula: duration ~ word.position + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
word. position	0.035025	0.017512	2	54.203	8.7381	0.0005137	***

p < .05 (*); p < .01 (**); p < .001 (***)

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	0.126903	0.014283	10.801702	8.885	2.71e-06	***
word. positioni	0.012725	0.008361	44.637387	1.522	0.13508	
word. positionm	-0.028574	0.010151	53.078957	-2.815	0.00683	**

p < .05 (*); p < .01 (**); p < .001 (***)

Estimated marginal means

contrast	estimate	SE	df	t.ratio	p.value	
final-initial	-0.0127	0.00856	52.1	-1.487	0.3056	
final-medial	0.0286	0.01047	61.6	2.729	0.0222	*
initial-medial	0.0413	0.01016	83.9	4.064	0.0003	*

p < .05 (*); p < .01 (**); p < .001 (***)

8.1.4 Postalveolar

Formula: duration ~ segment + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
segment	0.00037148	0.00037148	1	2.4525	1.4768	0.3282	

p < .05 (*); p < .01 (**); p < .001 (***)

8.2 Proportion voiced

8.2.1 Labiodental

Formula: propVoice ~ segment + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
segment	1.0423	1.0423	1	20.816	16.037	0.0006519	***

p < .05 (*); p < .01 (**); p < .001 (***)

Fixed effects:

	Estimate	Std Error	df	t value	Pr(>|t|)	
(Intercept)	0.4895	0.06062	24.32776	8.074	2.42E-08	***
segmentv	0.3832	0.09569	20.81579	4.005	0.000652	***

p < .05 (*); p < .01 (**); p < .001 (***)

Estimated marginal means

contrast	estimate	SE	df	t.ratio	p.value	
f-v	-0.383	0.0964	21.2	-3.974	0.0007	***

p < .05 (*); p < .01 (**); p < .001 (***)

8.2.2 Alveolar

Formula: propVoice ~ word.position + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
word. position	0.89372	0.44686	2	66.587	7.3288	0.001328	**

p < .05 (*); p < .01 (**); p < .001 (***)

Fixed effects:

	Estimate	Std Error	df	t value	Pr(>|t|)	
(Intercept)	0.44679	0.06669	14.04459	6.7	9.95E-06	***
word.positioni	-0.12558	0.05076	49.76399	-2.474	0.0168	*
word.positionm	0.08803	0.0609	70.13684	1.445	0.1528	

p < .05 (*); p < .01 (**); p < .001 (***)

Estimated marginal means

contrast	estimate	SE	df	t.ratio	p.value	
final-initial	0.126	0.052	62	2.416	0.0482	*
final-medial	-0.088	0.0626	85.8	-1.406	0.3425	
initial-medial	-0.214	0.06	113.4	-3.56	0.0016	**

p < .05 (*); p < .01 (**); p < .001 (***)

8.2.3 Postalveolar

Formula: propVoice ~ segment + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
segment	0.5645	0.5645	1	1.2307	11.439	0.1446	

p < .05 (*); p < .01 (**); p < .001 (***)

8.3 Duration voiced

8.3.1 Labiodental

Likelihood ratio test
Model 1: durfricvoice ~ (1 | speaker) + (1 | word)
Model 2: durfricvoice ~ segment + (1 | speaker) + (1 | word)

	#Df	LogLik	Df	Chisq	Pr(>Chisq)	
1	3	-128.35				
2	4	-124.21	1	8.2794	0.00401	**

p < .05 (*); p < .01 (**); p < .001 (***)

Formula: durfricvoice ~ segment + (1 | speaker) + (1 | word)

Fixed effects:

	Estimate	Std Error	z value	Pr(>|z|)	
(Intercept)	-0.8984	0.7147	-1.257	0.20875	
segmentv	-3.5453	1.3536	-2.619	0.00882	**

p < .05 (*); p < .01 (**); p < .001 (***)

8.3.2 Alveolar

Likelihood ratio test
Model 1: durfricvoice ~ (1 | speaker) + (1 | word)
Model 2: durfricvoice ~ word.position + (1 | speaker) + (1 | word)

	#Df	LogLik	Df	Chisq	Pr(>Chisq)	
1	3	-186.48				
2	5	-184.2	2	4.5631	0.1021	

p < .05 (*); p < .01 (**); p < .001 (***)

Likelihood ratio test
Model 1: durfricvoice ~ (1 | speaker) + (1 | word)
Model 2: durfricvoice ~ segment + (1 | speaker) + (1 | word)

	#Df	LogLik	Df	Chisq	Pr(>Chisq)	
1	3	-186.48				
2	4	-185.54	1	1.8726	0.1712	

p < .05 (*); p < .01 (**); p < .001 (***)

8.3.3 Postalveolar

Likelihood ratio test
Model 1: durfricvoice ~ (1 | speaker) + (1 | word)
Model 2: durfricvoice ~ segment + (1 | speaker) + (1 | word)

	#Df	LogLik	Df	Chisq	Pr(>Chisq)	
1	3	-37.576				
2	4	-35.896	1	3.3608	0.06677	

p < .05 (*); p < .01 (**); p < .001 (***)

8.4 Duration voiceless

8.4.1 Labiodental

Likelihood ratio test
Model 1: timevoicelessvoicing ~ (1 | speaker) + (1 | word)
Model 2: timevoicelessvoicing ~ word.position + (1 | speaker) + (1 | word)

	#Df	LogLik	Df	Chisq	Pr(>Chisq)	
1	3	-138.76				
2	5	-136.24	2	5.0384	0.08052	

p < .05 (*); p < .01 (**); p < .001 (***)

Likelihood ratio test
Model 1: timevoicelessvoicing ~ segment + (1 | speaker) + (1 | word)
Model 2: timevoicelessvoicing ~ (1 | speaker) + (1 | word)

	#Df	LogLik	Df	Chisq	Pr(>Chisq)	
1	3	-138.76				
2	4	-137.43	1	2.6598	0.1029	

p < .05 (*); p < .01 (**); p < .001 (***)

8.4.2 Alveolar

Likelihood ratio test
Model 1: timevoicelessvoicing ~ word.position + (1 | speaker) + (1 | word)
Model 2: timevoicelessvoicing ~ (1 | speaker) + (1 | word)

	#Df	LogLik	Df	Chisq	Pr(>Chisq)	
1	5	-163.98				
2	3	-166.77	-2	5.582	0.06136	

p < .05 (*); p < .01 (**); p < .001 (***)

Likelihood ratio test
Model 1: timevoicelessvoicing ~ (1 | speaker) + (1 | word)
Model 2: timevoicelessvoicing ~ segment + (1 | speaker) + (1 | word)

	#Df	LogLik	Df	Chisq	Pr(>Chisq)	
1	3	-166.77				
2	4	-165.90	1	1.7458	0.1864	

p < .05 (*); p < .01 (**); p < .001 (***)

8.4.3 Postalveolar

Likelihood ratio test
Model 1: timevoicelessvoicing ~ (1 | speaker) + (1 | word)
Model 2: timevoicelessvoicing ~ segment + (1 | speaker) + (1 | word)

	#Df	LogLik	Df	Chisq	Pr(>Chisq)	
1	3	-27.051				
2	4	-24.442	1	5.2187	0.02235	*

p < .05 (*); p < .01 (**); p < .001 (***)

Formula: timevoicelessvoicing ~ segment + (1 | speaker) + (1 | word)

Fixed effects:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	3.455	1.309	2.639	0.00832	**
segmentezh	-2.627	1.195	-2.198	0.02798	*

p < .05 (*); p < .01 (**); p < .001 (***)

8.5 Mean frequency

Formula: mean ~ segment + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
segment	63397463	10566244	6	132.97	6.6589	3.53E-06	***

p < .05 (*); p < .01 (**); p < .001 (***)

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	2810.1	484.11	13.83	5.805	4.79E-05	***
segmentezh	-916.58	1099.13	42	-0.834	0.409049	
segmentf	-529.79	275.51	235.58	-1.923	0.055695	
segments	848.54	297.75	142.53	2.85	0.005024	**
segmentT	-40.32	473	417.22	-0.085	0.932111	
segmentv	-1397.75	359.83	334.81	-3.885	0.000124	***
segmentz	120.75	326.83	169.66	0.369	0.712256	

p < .05 (*); p < .01 (**); p < .001 (***)

Estimated marginal means

contrast	estimate	SE	df	t.ratio	p.value	
esh-ezh	916.6	1099	49.3	0.834	0.9801	
esh-f	529.8	278	265.4	1.907	0.4776	
esh-s	-848.5	300	163.7	-2.83	0.0757	
esh-T	40.3	476	452.9	0.085	1	
esh-v	1397.8	363	369.6	3.852	0.0026	*
esh-z	-120.7	329	193.7	-0.367	0.9998	
ezh-f	-386.8	1102	49.1	-0.351	0.9998	
ezh-s	-1765.1	1099	48.9	-1.607	0.6788	
ezh-T	-876.3	1163	58.7	-0.753	0.9884	
ezh-v	481.2	1136	52.9	0.424	0.9995	
ezh-z	-1037.3	1108	50	-0.936	0.9647	
f-s	-1378.3	322	124	-4.284	0.0007	*
f-T	-489.5	421	683.6	-1.161	0.9082	
f-v	868	417	221.8	2.083	0.3663	
f-z	-650.5	351	148	-1.854	0.5141	
s-T	888.9	493	306.1	1.804	0.5462	
s-v	2246.3	420	182.7	5.342	<.0001	*
s-z	727.8	258	525.8	2.82	0.0735	

T-v	1357.4	566	349.4	2.4	0.2015	
T-z	-161.1	511	314.4	-0.315	0.9999	
v-z	-1517.5	443	197.9	-3.431	0.0128	*

p < .05 (*); p < .01 (**); p < .001 (***)

Formula: mean ~ poa + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
poa	40619810	13539937	3	247.41	8.4752	2.21E-05	***

p < .05 (*); p < .01 (**); p < .001 (***)

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	3428.38	477.35	13.51	7.182	5.75E-06	***
poadental	-741.25	497.37	344.01	-1.49	0.1371	
poalabiodental	-1381.81	291.26	109.07	-4.744	6.38E-06	***
poapostalveolar	-589.73	286.9	143.57	-2.056	0.0416	*

p < .05 (*); p < .01 (**); p < .001 (***)

Estimated marginal means

contrast	estimate	SE	df	t.ratio	p.value	
alveolar-dental	741	500	359	1.483	0.4486	
alveolar-labiodental	1382	293	116	4.715	<.0001	***
alveolar-postalveolar	590	289	153	2.041	0.1776	
dental-labiodental	641	436	728	1.469	0.4569	
dental-postalveolar	-152	482	589	-0.314	0.9893	
labiodental-postalveolar	-792	241	410	-3.291	0.006	**

p < .05 (*); p < .01 (**); p < .001 (***)

8.6 Standard deviation

Formula: stdev ~ segment + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
segment	19521346	3253558	6	134.99	4.0418	0.0009316	***

p < .05 (*); p < .01 (**); p < .001 (***)

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	1644.98	302.65	16.07	5.435	5.42E-05	***
segmentezh	-308.24	756.67	43.36	-0.407	0.685749	
segmentf	693.69	193.46	231.81	3.586	0.00041	***
segments	748.32	208.18	144.16	3.595	0.000445	***
segmentT	639.4	333.62	417.41	1.917	0.055973	
segmentv	-256.92	253.28	326.12	-1.014	0.31116	
segmentz	495.15	228.87	169.81	2.163	0.031903	*

p < .05 (*); p < .01 (**); p < .001 (***)

Estimated marginal means

contrast	estimate	SE	df	t.ratio	p.value	
esh-ezh	308.7	753	48.2	0.41	0.9996	
esh-f	-708.2	195	247.5	-3.628	0.0063	*
esh-s	-745.6	209	157.6	-3.565	0.0086	*
esh-T	-734.6	345	462.2	-2.127	0.3387	
esh-v	259.2	255	346.6	1.016	0.9502	
esh-z	-492.6	230	184.7	-2.14	0.334	
ezh-f	-1016.9	755	48.1	-1.347	0.8263	
ezh-s	-1054.3	753	47.9	-1.401	0.7988	
ezh-T	-1043.2	804	59.1	-1.297	0.8505	
ezh-v	-49.5	779	51.9	-0.063	1	
ezh-z	-801.2	759	49	-1.055	0.938	
f-s	-37.4	224	119	-0.167	1	
f-T	-26.4	306	701	-0.086	1	
f-v	967.4	292	207.6	3.317	0.0183	*
f-z	215.7	245	141.1	0.881	0.9749	
s-T	11.1	356	318	0.031	1	
s-v	1004.8	294	174.7	3.422	0.0134	*
s-z	253.1	182	494.9	1.39	0.8073	
T-v	993.8	406	350.4	2.447	0.1823	
T-z	242	369	322.6	0.655	0.9948	
v-z	-751.8	309	188.1	-2.43	0.192	

p < .05 (*); p < .01 (**); p < .001 (***)

Formula: stdev ~ poa + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
poa	8427734	2809245	3	264.31	3.5034	0.01599	*

p < .05 (*); p < .01 (**); p < .001 (***)

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	2325.95	300.66	15.94	7.736	8.74E-07	***
poadental	-129.89	355.76	355.59	-0.365	0.71524	
poalabiodental	-225.51	210.15	116.01	-1.073	0.28547	
poapostalveolar	-616.95	206.5	153.02	-2.988	0.00328	**

p < .05 (*); p < .01 (**); p < .001 (***)

Estimated marginal means

contrast	estimate	SE	df	t.ratio	p.value	
alveolar-dental	129.9	357	362	0.363	0.9836	
alveolar-labiodental	225.5	211	119	1.066	0.7106	
alveolar-postalveolar	616.9	208	157	2.967	0.0181	*
dental-labiodental	95.6	310	737	0.308	0.9899	
dental-postalveolar	487.1	344	602	1.417	0.4895	
labiodental-postalveolar	391.4	172	428	2.277	0.1051	

p < .05 (*); p < .01 (**); p < .001 (***)

8.7 Normalised intensity

Formula: norm.int ~ segment + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
segment	1937.1	322.85	6	66.283	16.515	1.55E-11	***

p < .05 (*); p < .01 (**); p < .001 (***)

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	-8.2755	1.4007	12.0408	-5.908	7.06E-05	***
segmentezh	-4.0079	2.1262	26.8482	-1.885	0.0703	
segmentf	-6.888	0.7207	81.3732	-9.557	6.05E-15	***
segments	-3.9578	0.74	70.5262	-5.348	1.04E-06	***
segmentT	-2.6383	1.3864	257.6355	-1.903	0.0582	
segmentv	-4.2396	0.9835	107.2657	-4.311	3.62E-05	***
segmentz	-3.4331	0.8211	66.2044	-4.181	8.71E-05	***

p < .05 (*); p < .01 (**); p < .001 (***)

Estimated marginal means

contrast	estimate	SE	df	t.ratio	p.value	
esh-esh	4.0079	2.128	37.8	1.884	0.503	
esh-f	6.888	0.729	111.5	9.445	<.0001	***
esh-s	3.9578	0.747	97.2	5.297	<.0001	***
esh-T	2.6383	1.396	325.2	1.89	0.4881	
esh-v	4.2396	0.995	145.2	4.263	0.0007	***
esh-z	3.4331	0.83	91.4	4.134	0.0015	**
ezh-f	2.8801	2.13	37.7	1.352	0.8228	
ezh-s	-0.0501	2.125	38	-0.024	1	
ezh-T	-1.3696	2.434	57.7	-0.563	0.9976	
ezh-v	0.2317	2.252	41.7	0.103	1	

ezh-z	-0.5748	2.156	38.5	-0.267	1	
f-s	-2.9302	0.769	84	-3.812	0.0047	**
f-T	-4.2497	1.313	519.5	-3.237	0.0217	*
f-v	-2.6484	1.064	103.4	-2.489	0.1741	
f-z	-3.4549	0.853	81.3	-4.051	0.0022	**
s-T	-1.3195	1.402	299.1	-0.941	0.9655	
s-v	0.2818	1.06	104.8	0.266	1	
s-z	-0.5247	0.743	184.7	-0.707	0.9921	
T-v	1.6013	1.595	243.8	1.004	0.9528	
T-z	0.7948	1.447	267.6	0.549	0.998	
v-z	-0.8065	1.119	99.3	-0.72	0.991	

p < .05 (*); p < .01 (**); p < .001 (***)

Formula: norm.int ~ poa + (1 | speaker) + (1 | word)

Type III Analysis of Variance Table with Satterthwaite's method

	Sum Sq	Mean Sq	NumDF	DenDF	F value	Pr(>F)	
poa	1575	525.01	3	125.12	27.2	1.30E-13	***

p < .05 (*); p < .01 (**); p < .001 (***)

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	-11.9992	1.3658	11.7315	-8.786	1.68E-06	***
poadental	2.3392	1.4497	290.8671	1.614	0.1077	
poalabiodental	-2.5091	0.7065	68.1941	-3.551	0.0007	***
poapostalveolar	3.3006	0.7228	78.9744	4.566	1.80E-05	***

Estimated marginal means

contrast	estimate	SE	df	t.ratio	p.value	
alveolar-dental	-2.339	1.457	328	-1.605	0.3772	
alveolar-labiodental	2.509	0.712	81.1	3.526	0.0038	**
alveolar-postalveolar	-3.301	0.729	93.7	-4.527	0.0001	***
dental-labiodental	4.848	1.373	558.5	3.53	0.0025	**
dental-postalveolar	-0.961	1.466	395	-0.656	0.9134	
labiodental-postalveolar	-5.81	0.682	169	-8.521	<.0001	***

p < .05 (*); p < .01 (**); p < .001 (***)

Appendix C: Classification trees

9.1 Duration

Figure A below shows the conditional inference tree for fricative duration. The following text provides an example of how the classification tree is to be interpreted.[7]

Each branching pair represents a significant ($\alpha = .05$) split in the data. The first significant split (node 1) in the data is between /f, s, z, ʃ, ʒ/ on the one hand and /θ, v/ on the other, with the latter group generally having shorter durations than the former ($p < .001$). Within the /θ, v/ group there is a second significant split (node 19) with those preceded by front vowels, F2 > 1745.28 Hz, being generally longer than those preceded by vowels with second formants at or below this threshold ($p < .001$).

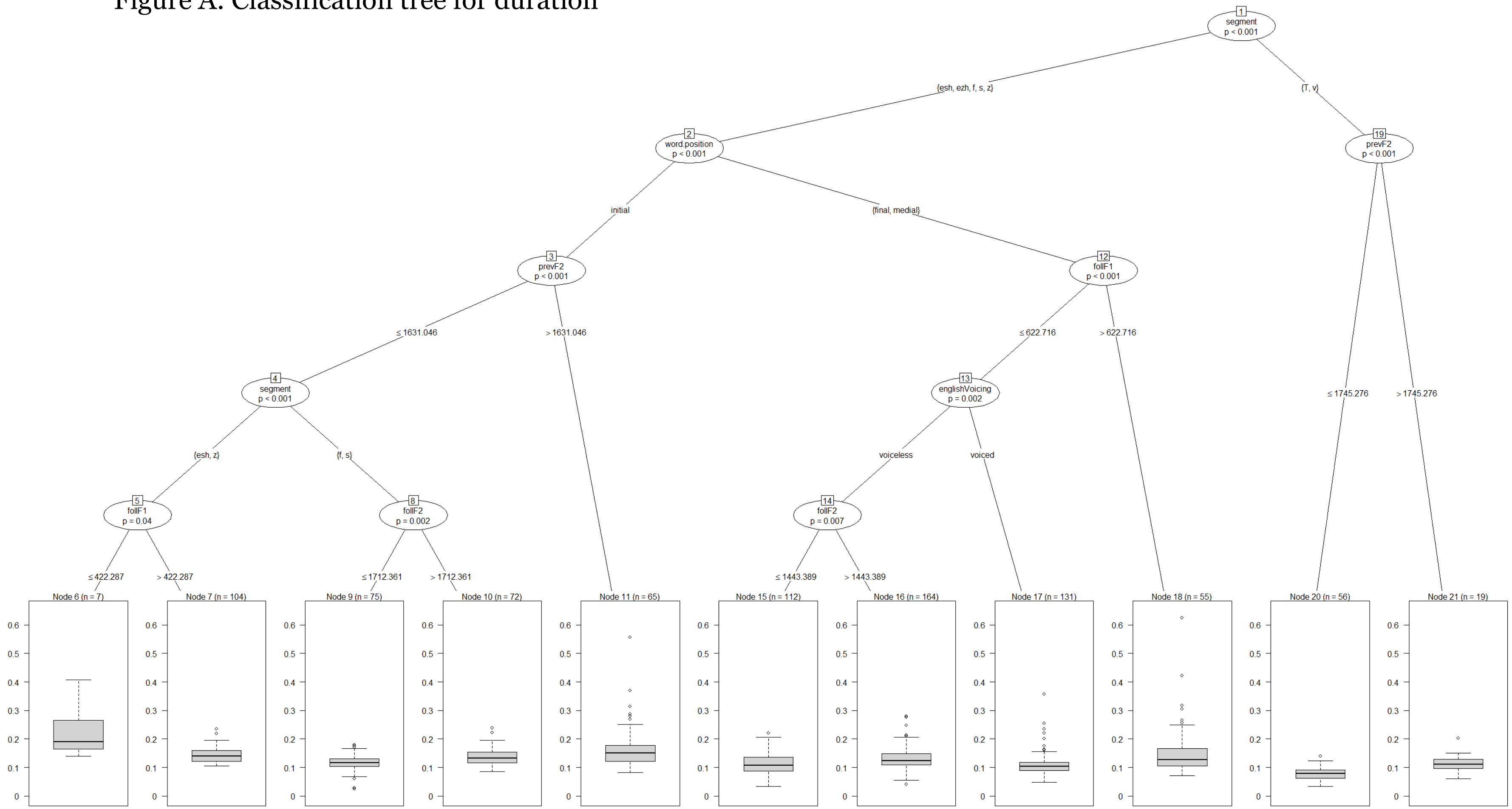
Within the /f, s, z, ʃ, ʒ/ group, the second significant split comes down to word position (node 2, $p < .001$). Final and medial fricatives group together in opposition to initial fricatives, with the former having generally shorter durations than the latter. Within the {final, medial} group, there is a split between those followed by a low vowel, F1 > 622.72 Hz, and those followed by vowels with first formants at or below this, with the former having generally longer durations than the latter (node 12, $p < .001$). Within the latter non-low following vowel group, there is a significant split along whether the fricative is voiced or voiceless in

[7] Readers on a computer should be able to zoom in for better clarity.

English (node 13, $p = .003$). The fricatives that are voiced in English have generally shorter durations. There is a final split within the voiceless English fricatives in this group (/f, s, ʃ/), such that those followed by a front vowel, F2 > 1443.39, are generally longer than those followed by vowels with second formants below this (node 14, $p = .007$).

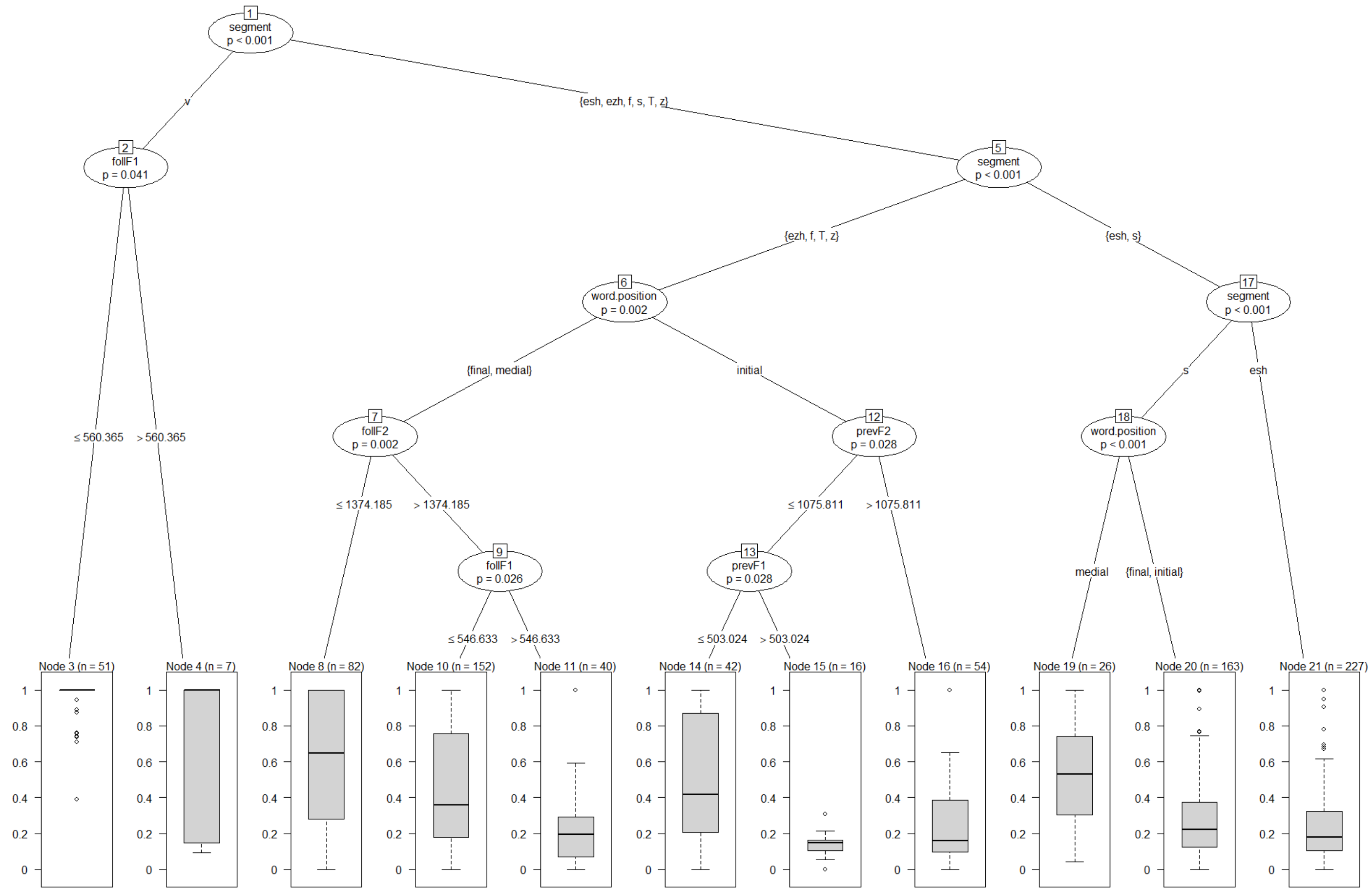
Returning to word-initial /f, s, z, ʃ, ʒ/, the next significant split in this group is between those preceded by front vowels, F2 > 1631.05 Hz, and those preceded by vowels with second formants below this (node 3, $p < .001$). The former group appears to have generally longer durations than the latter. Within the non-front vowel group, the next significant split is between /ʃ, z/ on the one hand and /f, s/ on the other (node 4, $p < .001$). Within the /f, s/ group, there is a final split between those followed by front vowels, F2 > 1712.36, and those followed by vowels with second formants below this (node 8, $p = .002$), with the former having generally longer durations. Finally, there is a split within /ʃ, z/ group such that those followed by high vowels, F1 ≤ 422.29 Hz are generally longer than those followed by non-high vowels (node 5, $p = .04$). Place of articulation did not produce a significant split.

Figure A: Classification tree for duration



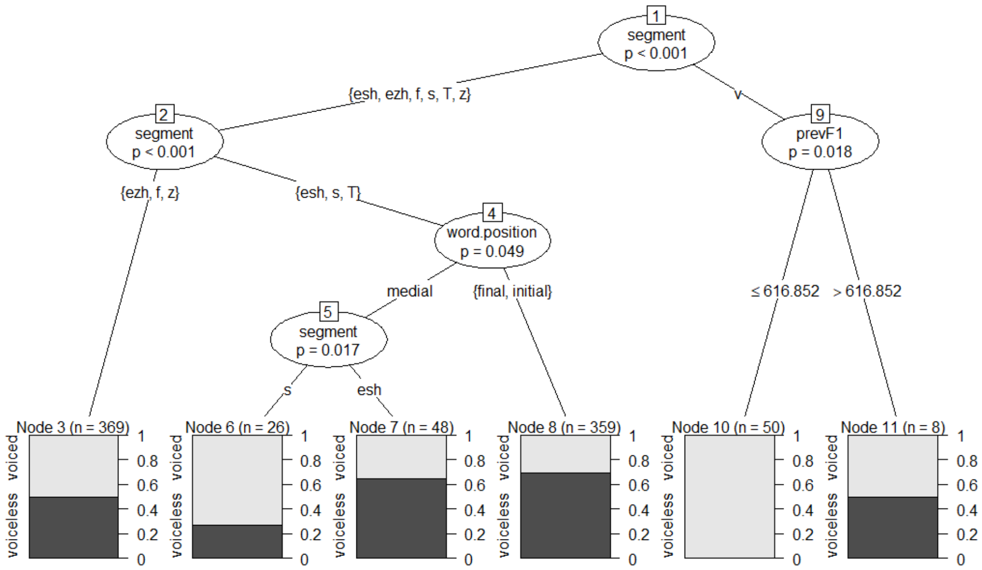
9.2 Proportion voiced

Figure B: Classification tree for proportion voiced



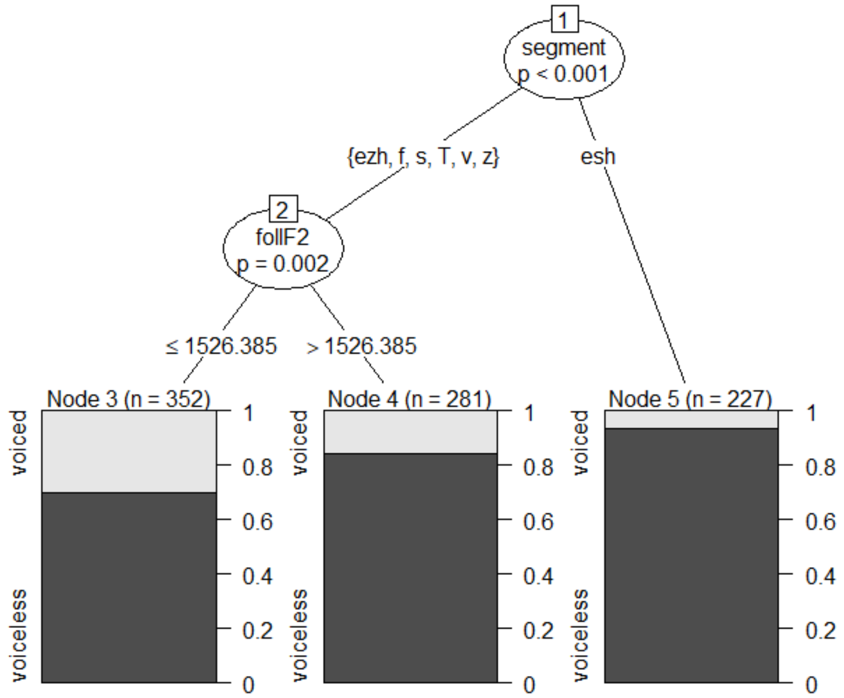
9.3 Duration voiced

Figure C: Classification tree for duration voiced



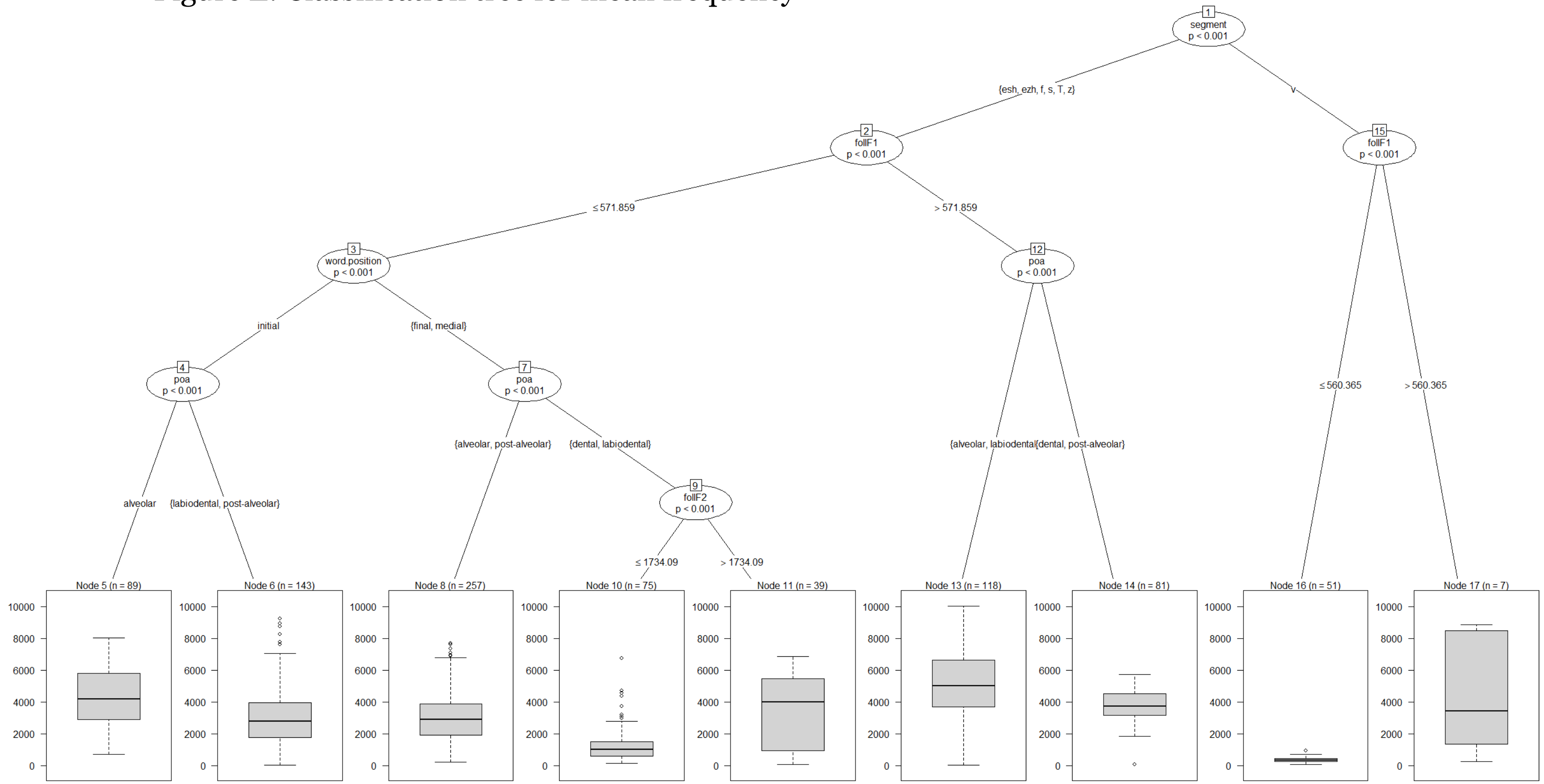
9.4 Duration voiceless

Figure D: Classification tree for duration voiceless



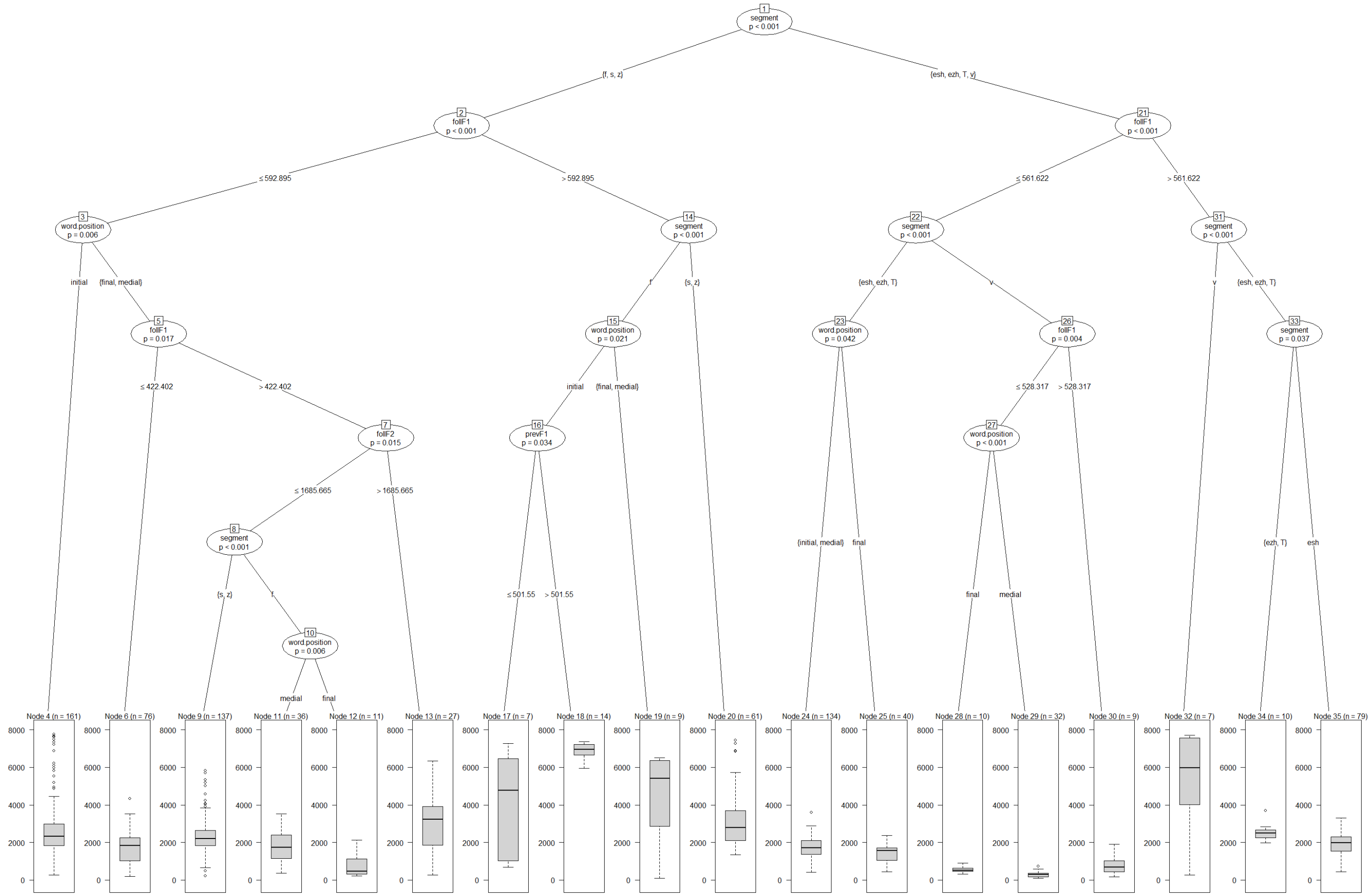
9.5 Mean frequency

Figure E: Classification tree for mean frequency



9.6 Standard deviation

Figure F: Classification tree for standard deviation



9.7 Normalised intensity

Figure G: Classification tree for normalised intensity