POSSIBLE CONSTRAINTS ON ALLOPHONIC VOICING IN AUSTRALIAN ABORIGINAL LANGUAGES: EVIDENCE FROM BARDI, KAYARDILD, WARLPIRI, AND YAN-NHANGU

By

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ABSTRACT

Many Australian Aboriginal languages have a single phonological stop series, although others have been reported to distinguish at least two stop series. The nature of the stop contrasts in Australian languages has been variously described as that of voicing (Austin 1988), fortis/lenis (Butcher 2004), length (Evans & Merlan 2004), or even a combination of factors (Evans 1996). Few studies, however, address the nature of allophonic stop variation that is also present throughout the Australian languages, and even fewer studies attempt to compare phonetically the stops from languages across the Australian continent. This work addresses these important gaps in the literature and attempts to shed insight onto phonetics of Australian languages in general. To this end, several sound files from four representative Australian languages were examined: Bardi, Kayardild, Warlpiri, and Yan-Nhangu. After segmenting these files into individual words, I observed the phonetic context, broadly defined, in which the stops of the language occur. Then I took several acoustic measurements: VOT, VTT, stop to release duration, and total stop duration. The data appear to support the idea that stop allophony is contextually conditioned. Furthermore the degree of persistent voicing in otherwise "voiceless" stops in the data may also confirm the model of passive devoicing (Anderson & Maddieson 1994). However, these conclusions remain tentative until more data can be gathered and analyzed.

1.0 INTRODUCTION

The Australian Aboriginal languages show remarkable phonological and phonotactic similarities across the Australian continent. A number of these similarities are readily demonstrable and unique compared to the other languages of the world. For example, many Australian Aboriginal languages have small vowel inventories— typically /a/ /i/ /u/, no fricative phonemes, and anywhere up to seven distinct places of articulation, although many have five or six places of articulation (Butcher 2006:190-191, Dixon 1980: 129-135, Bowern p.c.). Prior to European contact, the Australian continent boasted about 700 Aboriginal groups using 250 languages. These Aboriginal languages developed in relative isolation from the other languages of the world (Gaby 2008:212). These languages are divided between the Pama-Nyungan languages, occupying roughly seven-eighths of the continent, and the Non-Pama-Nyungan languages (Evans 1996:724). A typical Australian phoneme inventory is exemplified in Kayardild as follows, which is written in both practical Australianist[1] and IPA orthography:

Consonants

	Bilabial	Laminodental	Apicoalveolar	Laminopalatal	Retroflex	Dorsovelar
Stop	p /p/	th /t̪/	t /t/	ty /c/	rt /ʈ/	k /k/
Nasal	m /m/	nh /n̪/	n /n/	ny /ɲ/	rn /ɳ/	ng /ŋ/
Lateral			l /l/			
Trill			rr /r/			
Approximant	w /w/			y /j/	r /ɹ/	

Vowels

	front		back
high	i, i:		u, u:
low		a, a:	

Table 1. Phonemic Inventory of Kayardild, a Non-Pama-Nyungan language

[1] The practical orthography will be used for the stops /p, th, t, ty, rt, k/ in the following sections of this work. The corresponding voiced series will be written as follows: b, dh, d, dy, rd, g.

As one can demonstrate, Kayardild possesses the typical three vowel contrast with a vowel length distinction, six places of articulation, and does not have any fricatives in its inventory, although fricatives do appear as variant forms of stops (Round 2009:52).

Kayardild also illustrates the general observation across Australian languages that there is only a single stop series that typically does not contrast for voicing or duration. Hence if one is speaking Kayardild one can in principle pronounce the word for 'woman' *maku* as either [maku] or [magu] with no change in meaning, as /k/ and /g/ are not separate phonemes of the language. On the other hand, there exist Australian languages with two stop series—perhaps up to 30%— where this generalization does not hold (Butcher 2004:550). In such cases the voiced and voiceless stop series may in fact contrast phonemically. Austin (1988) provides the example of the Gugu Uwanh minimal pairs illustrating such a phonemic contrast: *aku* means 'skin', while *agu* means 'ground.'

The phonotactic patterns of Australian languages are also remarkable in that a typical word in an Australian language is at least two syllables long. Thus a prototypical phonological word would be of the form $C_{INITIAL}VC_1(C_2)V(C_{FINAL})$. The phonological voicing contrast typically restricted to the word-medial $C_1(C_2)$ position, although it can appear in other positions (Dixon 1980:127). In addition, the word-medial position is often the only position that allows consonant clusters (Butcher 2006:205). No Australian language has a voicing contrast in all consonantal positions (Austin 1988, Butcher 2006:193).

1.1 The "Voicing" Contrast in Australia

In discussing voicing contrasts, it is essential to distinguish the phonetic aspect of "voicing," which is directly measurable to the acoustic signal, from its associated phonological dimension, which is abstracted away from the signal, for example in setting up phonological contrasts. In the phonetic literature, stop voicing is defined by the concomitant vibration of the vocal cords creating the relevant glottal pulsing that is perceivable in the acoustic signal of the stop (Butcher & Reid 1989:6). From an articulatory standpoint, this vibration arises from a pressure differential created by the lungs which forces outgoing air through the narrow opening of the vocal cords. An absence of such concomitant vocal cord

vibration, for example in the case of the vocal folds being too far apart, thus characterizes the voiceless stop (Ladefoged & Maddieson 1996:52). Voicing effects are measured in terms of the voice onset time (VOT), defined as the time from the release of the stop to the resumption of regular voicing. In voiceless stops, VOT corresponds to the length of the aspirated segment following the stop's release, whereas in voiced stops, VOT corresponds to the duration of regular voicing prior to the release and is thus negative (Ladefoged & Cho 2001:1). Voicing contrasts, in about half of the world's languages where the stop contrast is phonological, employ different target VOT's for the stop distinction (Butcher & Reid 1989:6).

Although it is possible to differentiate voiced/voiceless stops by the maintenance of different VOT's, it is not the case that these target VOT's are consistent either across or within languages. In an investigation of VOT across 18 languages, Ladefoged & Cho (2001) observed that human languages do not appear to converge on a common target VOT for each of their voiced and voiceless stops. Instead much variation in VOT was observed, not only across languages as each language community settles on its own target VOT values, but also within languages and across speakers as a result of other factors, like

Language	Bilabial	Dental	Alveolar	Retroflex	Velar	Uvular
Aleut (Eastern)			59		75	78
Aleut (Western)			76		95	92
Apache	13		15		31	
Apache (aspirated)			58		80	
BanawaH		22			44	
Bowiri	17		18		39	
Chickasaw	13		22		36	
Dahalo	20	15	42		27	
Defaka	18		20		30	
Gaelic	13	22			28	
Gaelic (aspirated)	64	65			73	
Hupa	11	16			44	27
Hupa (aspirated)		82			84	
Jalapa Mazatec			11		23	
Jalapa Mazatec (aspirated)			63		80	
Khonoma Angami	10	9			20	
Khonoma Angami (aspirated)	83	55			91	
Montana Salish	22		24		48	55
Navajo	12		6		45	
Navajo (aspirated)			130		154	
Tlingit			18		28	30
Tlingit (aspirated)		120			128	128
Tsou	11		17		28	
Wari'	19	26			50.58	
Yapese	20	22			56	

Table 2. Mean VOT stop values showing considerable variation in VOT (Source: Ladefoged & Cho 2001)

phonetic environment and natural variations in vocal tract physiology (Ladefoged & Cho 2001:8). The mean VOT values gathered by for the languages are reproduced in Table 2.

While Australian Aboriginal languages with two stop series can be analyzed as having a contrast in voicing, recent phonetic research on Australian languages have called this assumption into question. A handful of Australian languages do not consistently make a distinction in their target VOT's for their two stop series (Butcher & Reid 1989:7). In fact, the phonological stop contrast may be linked to a combination of phonetic correlates, including voicing, stress, and vowel length (Evans 1996:730). For example, the primary phonetic cue for the stop contrast for Jawoyn is stop duration. From acoustic data in Jawoyn Evans & Merlan (2004:200) cite the word for 'frog' *jatti* as phonetically [jat:i], with the stop possibly analyzable as a geminate. This is in contrast to the word for 'tributary' *jateng,* which is [jadeŋ]. Yet this length distinction is not necessarily a perfect phonetic correlate of the phonological contrast, as a certain degree of duration variability exists. For instance, the word 'spouse/in-law' *kakkali* is reported to be pronounced either as [gagali] or [gak:ali] among Jawoyn speakers, although Evans & Merlan do not cite the actual stop durations for these particular phonetic impressions (Evans & Merlan 2004:200).

Butcher (2004) argues for yet another model of the contrast: lenis/fortis. The lenis/fortis stop distinction most famously appears in the study of various Korean dialects (see Cho et al 2002). The conceptual distinction between lenis/fortis is that fortis stops are produced with more respiratory effort and tension than their lenis counterparts (Cho et al 2002:194, Stoakes et al 2007:869). In contrast with voicing and its VOT, however, the lenis/fortis contrast is not as well defined in terms of the phonetic correlates, and this fact necessitates finding indirect phonetic correlates that hint at the lenis/fortis quality of stops. From the acoustic and articulatory data in the Aboriginal languages Burarra, Murrinh-Patha, and Bininj Gun-Wok, it can be argued that differences in the duration of the stop closure and peak intra-oral pressure in the two stop series correlate roughly with the underlying "effort" and "tension" of the lenis/fortis contrast in these Australian languages (Butcher 2004:556, Stoakes et al 2007:869). Despite the recent theoretical models of Australian stop contrast presented here, this work will, for convenience's sake, continue the tradition of analyzing phonemically "voiced" and "voiceless" stops with one important

caveat. The phonetic work on Australian languages has already revealed that a lot of related phenomena can be hidden in a simple phonological voicing distinction.

This present work will attempt to address allophonic voicing, a phenomenon that cannot be understood from the phonological voiced/voiceless contrast model alone. It is traditionally assumed that in most languages with a single stop series the stops are phonetically voiceless. Certainly this is the case in Polynesian languages like Hawaiian, Tongan, and Maori, where the stops all appear to be articulated with open vocal cords (Ladefoged & Maddieson 1996:53). While Aboriginal Australian languages with only one stop series typically have their stops described as voiceless and unaspirated, there are languages where this generalization does not hold (Hamilton 1996:54). Some Australian languages, like Yidiny, Wambaya, and Yuwaalaraay, are described as having regularly voiced stop allophones for its stop series, with voiceless allophones sporadically manifesting in some contexts (Hamilton 1996:54).

These "voiced-stop" languages are remarkable until one considers another common pattern of many Australian languages with a single stop series: many stops in these languages are not phonetically completely voiced or voiceless, but rather "partially voiced." Such partially voiced stops usually are recognizable word medially and have a common pattern of having a voiced portion at the onset of the closure that fades into voicelessness. Such initial voicing may persist approximately 50 ms into the stop, as reported in the Northern Territory language Tiwi (Anderson & Maddieson 1994:143). On an articulatory level, this may be due to the lack of an active laryngeal opening gesture, like in Polynesian languages, that would ensure the voicelessness of the stop, allowing residual voicing from the previous segment to carry into the stop (Ladefoged & Maddieson 1996:54). An example of such a partially voiced stop is illustrated in Figure 1, where the voicing from the vowel persists well into the dental stop.

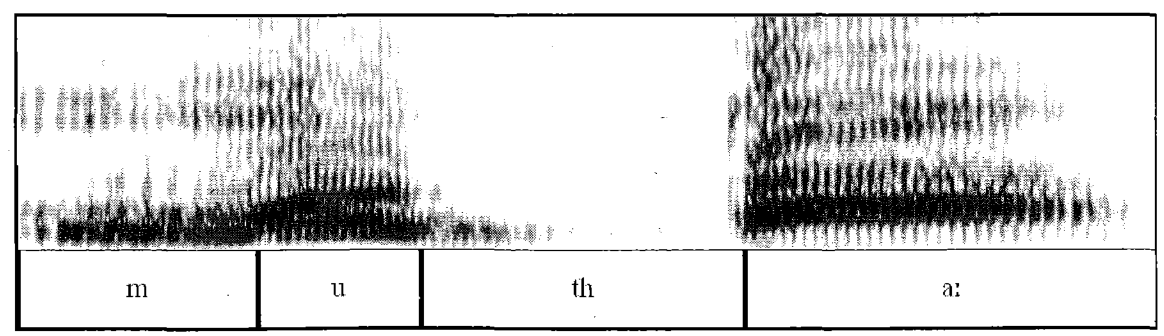

Figure 1. Partial voicing is evident in the stop in Kayardild word *muthaa* (many)

With so much variation in the reported voicing of stops across Australian Aboriginal languages, even in languages without the phonological voicing contrast, it is striking that little in the way of comparative, instrumental analysis has been carried out to date on the allophonic voicing effects in Australian languages. This present work hopes to address this gap in the literature and open up this field of research to instrumental phonetic investigation and new insights on Australian Aboriginal languages.

1.2 Allophonic Voicing in Australian Languages: Hypotheses

Although allophonic voicing effects in Australian stops have often been reported in languages with one stop series, the underlying cause of this allophony is currently not well understood. The simplest explanation for this allophony is to assume that all allophonic forms of these Australian stops occur in free variation. For instance, speakers of these languages can use anything available from [p] to [b] for their labial stop and anything from [k] to [g] for their velar stop. Since the typical Australian language also has no phonemic fricatives, one also has available the (typically voiced) spirantized approximations [β] and [ɣ] as other allophones of the labial and velar stop, respectively (Hamilton 1996:55). Hence, speakers can choose on arbitrary or extralinguistic grounds which stop allophones they want to employ in their speech at any given moment. While of course there may be impressionistic tendencies observed for certain allophones produced in certain contexts, these tendencies need not bother one working under the free variation assumption. With some reservations, Dixon (1980) typifies this free variation model in his remarks on Dyirbal pronunciation:

> [diban], [tiban] are the two commonest pronunciations of 'stone.' [dipan], [tipan] are heard much less often; but they are, unhestitatingly, taken as instances of the same word since any allophone CAN be substituted for another allophone of the same phoneme, without changing the meaning of the word. (127)

Free variation is certainly plausible in explaining the allophonic voicing in the Australian languages without a voicing contrast. After all, Dyirbal speakers could in principle interpret with little difficulty the words of another speaker who regularly alternated between [diban], [tiban], [dipan], and [tipan] forms,

and so in that sense the voicing of the stops in that word could be freely decided according to a speaker's preference. In addition, it is likely that the context of the utterance can affect the stop's realization. For example, a stop appearing in a word in citation form may very well vary from the same stop appearing in continuous speech. However, if one assumes only free variation at work, then one cannot predict anything about Dixon's "commonest pronunciations" of words with their target VOT's. After all, under a free variation framework, one would predict that all allophones are permitted in all environments.

Another explanation for allophony is to assume that there exists an underlying normative articulation (like voiceless unaspirated plosive) for voicing and manner for all the stops of Australian languages. For instance, one can decide that [p, b, β] are all representations of the stop that is typically [p] and [k, g, ɣ] are all representations of the stop that is typically [k], with the allophonic variants arising from some phonologically derived environments: for example, we can suppose that voiced stops surface only in an intervocalic environment, like the [b] in Dixon's [tiban] example. While this hypothesis creates testable predictions on allophonic distribution, like which allophone is most likely to surface phonetically in what environment, several remarks remain to be made regarding this normative articulation hypothesis. It is of course premature to assume that for Australian languages the normative stop articulation is always the voiceless unaspirated plosive allophone. In languages with most stops phonetically voiced, as in Yidiny, we would likely draw the conclusion that in such a language the allophones [p, b, β] would all represent [b] instead of [p]. Each language in Australia would be able to choose their normative articulation in this way.

A related approach to explain allophonic voicing in Australian languages with one stop series is to assume that these stops have no "underlying" voice value and thus are phonologically underspecified for voicing. According to a phonological analysis based on underspecification, the realizations of the stops would not be arbitrary, with the voicing parameter largely dependent on either universal or language specific principles. For example, if one observes that Australian stops tend to voice in intervocalic position, then one can formulate the rule: [+stop] → [+voice] / V_V. While it is possible to make precise predictions like this one according to the rules of underspecification, an inadequacy with this framework, and other phonological approaches to allophonic voicing, is that the phonetic reality of Australian stops is often more complex than a binary [±voice] parameter that needs to be filled. In particular, these quasi-phonological approaches have little to say about the "partial voicing" effects on the phonetic level reported in many Australian languages.

A final approach for allophony is the passive devoicing model. In this model, the stops in Australian languages are produced with no actual laryngeal opening gesture, so the voicing from the previous voiced segment, like a vowel, can passively persist well into the start of the stop until it fully devoices due to passive cavity expansion (Ladefoged & Maddieson 1996:54). Hence, the continuum of voiceless to voiced stops is a direct product of voicing duration from the preceding segment carrying over into the stop. This model, which relies primarily on the phonetic environment and intrinsic phonetic properties of stops, creates many testable predictions about the distribution of allophonic forms. For example, we can predict that the maintenance of stop voicing in such a model should be affected by both stop duration and place of articulation. In particular, it is harder to maintain voicing passively through a longer stop, like a geminate, than a shorter stop, because the pressure differential provided by air escaping through the vocal cords can only be maintained for so long before the air supply maintaining voicing runs out. In addition, it is harder to keep a stop articulated at the back of the mouth, like a /k/, voiced than a stop articulated at the front, like a /p/, because of the differing sizes of the cavity behind the oral constriction (Hayes & Steriade 2004:12-13).

From the previous discussion and the literature it encompasses, it is clear that there is still much to be learned and refined from the study of allophonic voicing effects in Australian languages. Certainly none of these models of allophonic voicing need to be rejected a priori, and none of these models are mutually exclusive. This present work will consider the hypotheses presented here using data from several Australian languages and provide some insight as to some possible phonetic constraints to such stop allophony.

2.0 RESEARCH METHODS

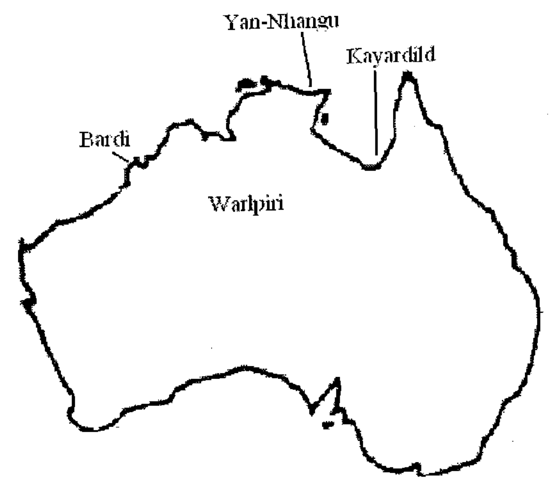

Figure 2. Geographic distribution of languages investigated in this work

While a detailed Australia-wide survey of languages would be too ambitious for the scope of this work, it was of great interest for the investigation of allophonic voicing effects to choose a sample of Australian languages that are as representative of the linguistic, phonological, and phonotactic variety across the Australian continent as possible. In this work, the languages under investigation consisted of Bardi, Kayardild, Warlpiri, and Yan-Nhangu. These languages were far from being representative of the Australian continent, and they were chosen primarily because ample phonetic data was available to investigate these languages in depth. Nevertheless, these four languages have individual differences of interest. For example, Yan-Nhangu and Warlpiri are Pama-Nyungan languages, whereas Bardi and Kayardild are Non-Pama-Nyungan. It is also interesting to note that while Kayardild and Yan-Nhangu have all six places of articulation /p, th, t, ty, rt, k/ for their phonemic stop inventory, Bardi and Warlpiri only have five, as they only have a single laminal stop (laminopalatal /ty/) and lack the laminodental stop /th/.

Of these four languages, only Yan-Nhangu is described to have a phonological voicing contrast (Baymarrwanga et al 2008:34). Yan-Nhangu thus can serve as a control case to compare against the languages with only one stop series. After all, this language should be expected to exhibit less variation in the voicing parameter compared to the languages without a voicing contrast, since voicing is phonologically contrastive in Yan-Nhangu.

2.1 Speakers and Sources

Utterances from speakers of these four languages were gathered from various sound files from field recordings and learner's guides. Both the field recordings and the learner's guides contained a collection of directly elicited forms as well as dialogues in the respective languages. The audio files were segmented into smaller files containing individual word tokens, the stops in which then transcribed and analyzed using Praat software (Boersma & Weenink 2006). As this work was particularly interested in the phonetic environment surrounding allophonic voicing effects, and the word-medial position is the only position where relevant voicing contrasts and a variety of phonetic environments can be investigated, only word-medial or intervocalic stops were used as tokens in this work. Because initial and final stops are subject to different phonological and phonetic constraints than those in word-medial position, they were not explored in this work. The speakers and sources are summarized in detail in Table 3.

Language	Number of speakers	Source	Type	# Tokens
Bardi	1 speaker	Bowern	Field Recording	130
Kayardild	7 speakers	Round	Field Recording	142
Warlpiri	3 speakers	Laughren et al (1996)	Learner's Guide	186
Yan-Nhangu (YN)	4 speakers	Bowern	Field Recording	207

Table 3. Speaker and source information on the languages studied in this work

The data was not normalized for speech rate variation or elicitation type, both factors which could confound this work's findings. First, no carrier phrase existed with which to compare speech rate consistently across the duration of the tapes. Normalization according to elicitation type (e.g. direct word elicitation versus spontaneous word forms in dialogue) was considered but ultimately was rejected because of the unbalanced distribution of tokens by each elicitation type.

Natural variation across speakers was also considered as a confounding variable to this study. To investigate how much of a potential confound that inter-speaker differences contribute to the data, several measurements, including VTT, VOT, and stop duration[2], were compared across speakers in Warlpiri. Warlpiri was chosen out of the four languages investigated because the number and distribution of tokens across all places of articulation was roughly comparable among the three speakers CH, KH, and TR. The distribution of the data was graphed in Figures 3, 4, and 5 on the next page.

[2] See 2.1.1 for a further description of what these variables measure.

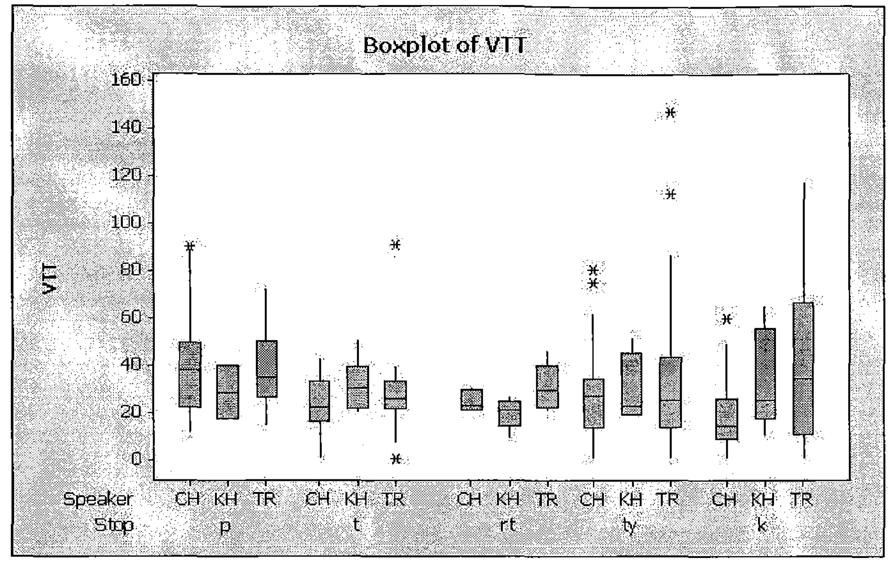

Figure 3. Boxplot of VTT values (ms) among three speakers in Warlpiri

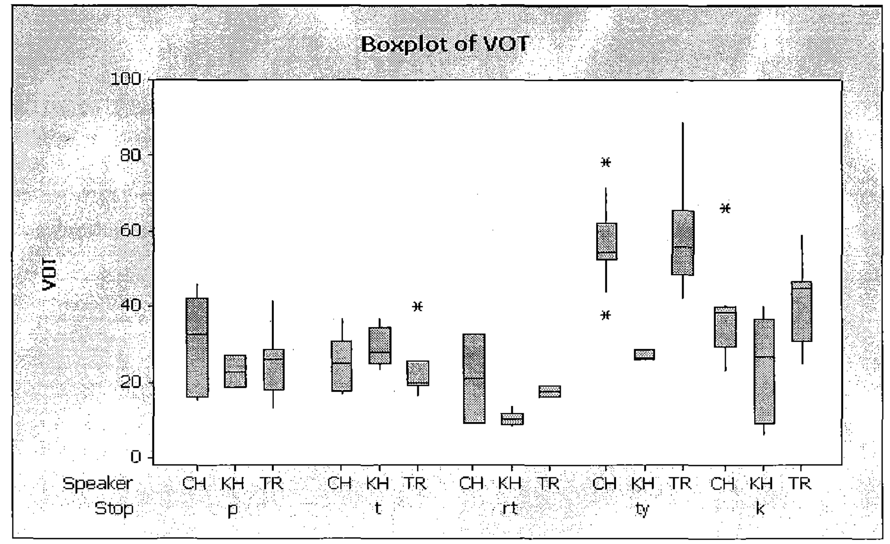

Figure 4. Boxplot of VOT values (ms) among three speakers in Warlpiri

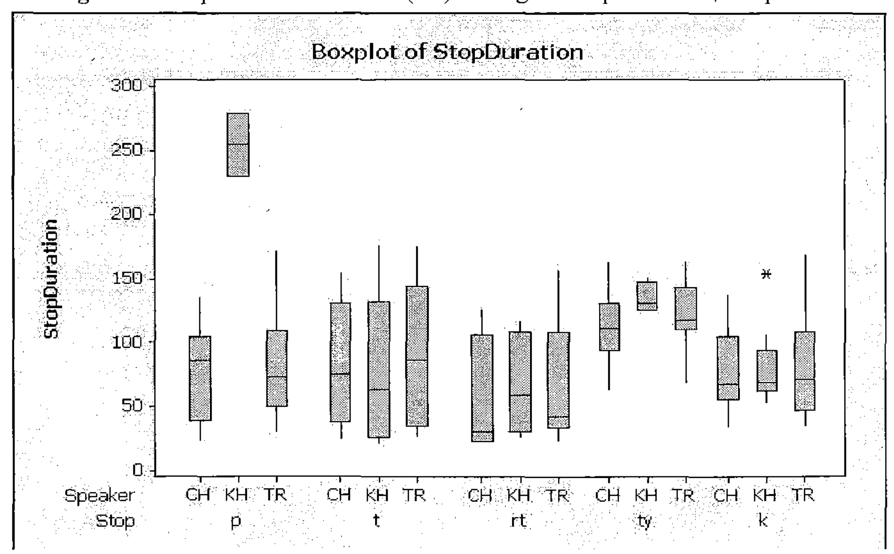

Figure 5. Boxplot of stop duration values (ms) among three speakers in Warlpiri

Several particular distributions of note were the VOT duration of speaker KH's /ty/ and the stop duration of speaker KH's /p/. The median of KH's VOT for /ty/ was about 30 ms, whereas the median of the other speaker's VOT for /ty/ was about 50 ms. The source of the anomaly located in four /ty/ tokens with relatively short VOT durations. Meanwhile, the median value of KH's /p/ was about 250 ms, in contrast to the other /p/ values with median values < 100 ms (see Figure 5). Upon closer investigation, the source of this anomaly was located in two /p/ tokens in the Warlpiri word *ngapa* 'water,' where the /p/ was confirmed to have an unusually long duration. Nevertheless, despite the existence of some outlier values like KH's /ty/ and /p/ tokens, the overall distribution of these box-plots, clustered around common values, suggest that speakers, at least in Warlpiri, seemed consistent in their overall articulations of the stops. While this inter-speaker investigation was only representative of a subset of speakers in this study, one could tentatively conclude that inter-speaker differences are probably not variable enough to confound the other variables studied in this work.

2.2 Parameters

Because actual speakers were not available, it was only possible to consider the acoustic, not aerodynamic parameters of the allophonic voicing contrast. Since this work studied the phonetic constraints behind allophonic voicing effects of various stops, the independent variables that were of most interest concerned the place articulation of the stop and its phonetic environment, broadly defined. Two particularly salient features of the phonetic environment that were investigated were the stop's preceding segment and syllabic position, both of which have the potential to affect the dependent variables of interest in this work.

2.2.1 Independent Variables

As was previously observed in certain Australian languages, partial voicing effects depend on voicing that is carried over from preceding segment that passively devoices into the stop (Anderson & Maddieson 1994: 143). As the nature of the preceding segment could determine the amplitude and degree

of partial voicing in the stop's phonetic realization— for example, more sonorous segments like vowels could passively persist into the stop longer than less sonorous segments like liquids and nasals— it was important that all word tokens were coded for preceding segment. The categories of preceding segment were coded as follows: V (vowel), L (lateral), R (rhotic), and N (nasal). Note that this notation, when applied to L, R, and N, describes a natural consonant cluster, whereas V describes a stop in intervocalic position. For example, if one wants to discuss a stop with the preceding segment of N, then that is equivalent to discussing a nasal-stop cluster. Selected examples demonstrating each preceding segment are illustrated in Table 4.

Preceding Segment	Bardi	Kayardild	Warlpiri	Yan-Nhangu
V	a**g**al	ngu**k**u	paka**k**a	nha**k**un
L	dal**g**a	dul**k**i	kul**k**urru	rul**k**a
R	rirr**g**a	karr**k**ar	karr**k**u	gurr**k**u
N	bin**k**arr	kun**k**u	pirn**k**i	nhan**k**u

Table 4. Examples of word tokens containing the velar stop sorted by preceding segment values

The stop's syllabic position was another independent variable investigated in this work, coded as C1, C2, C3, etc., where C1 represents any initial consonant onset joined to the first syllable, C2 represents any consonant associated with the second syllable, and so on. Hence, the velar stop in the Bardi words *agal* 'and' and *dalga* 'cowrie shell' were coded as C2, whereas *bilanggamarr* 'helicopter tree' was coded as C3. In this work, syllabic position was an indirect indicator of the degree of stress of the syllable that may affect the quality of the stop. In all languages in the sample, stress was always initial and associated with the syllable associated with C1 position. Thus, C2 always described the syllable associated with post-stress position, and C3 always described the syllable associated with the next position, and so on.

2.2.2 Dependent Variables: VOT, VTT, Stop Closure to Release, etc.

Each sound file containing a word token was individually labeled with 5 interval tiers in Praat. The measures of interest taken included the entire duration of stop closure to the release of the articulators (see 1 at Figure 6), voice onset time (VOT): the duration from the release of articulators to the resumption of regular voicing (2 at Figure 6), and voice termination time (VTT)[3]: the duration of the transition state from the end of regular voicing up to the final closure of the articulators (3 at Figure 6). Durations were measured visually using time-aligned waveform and spectrogram windows. Other measures that were taken include the duration of the preceding segment and the total stop duration (calculated by summing up 1 and 2 in Figure 6). As mentioned earlier, many variables could affect the durations measured in this study: preceding segment, syllabic position, speaker variation, and so on.

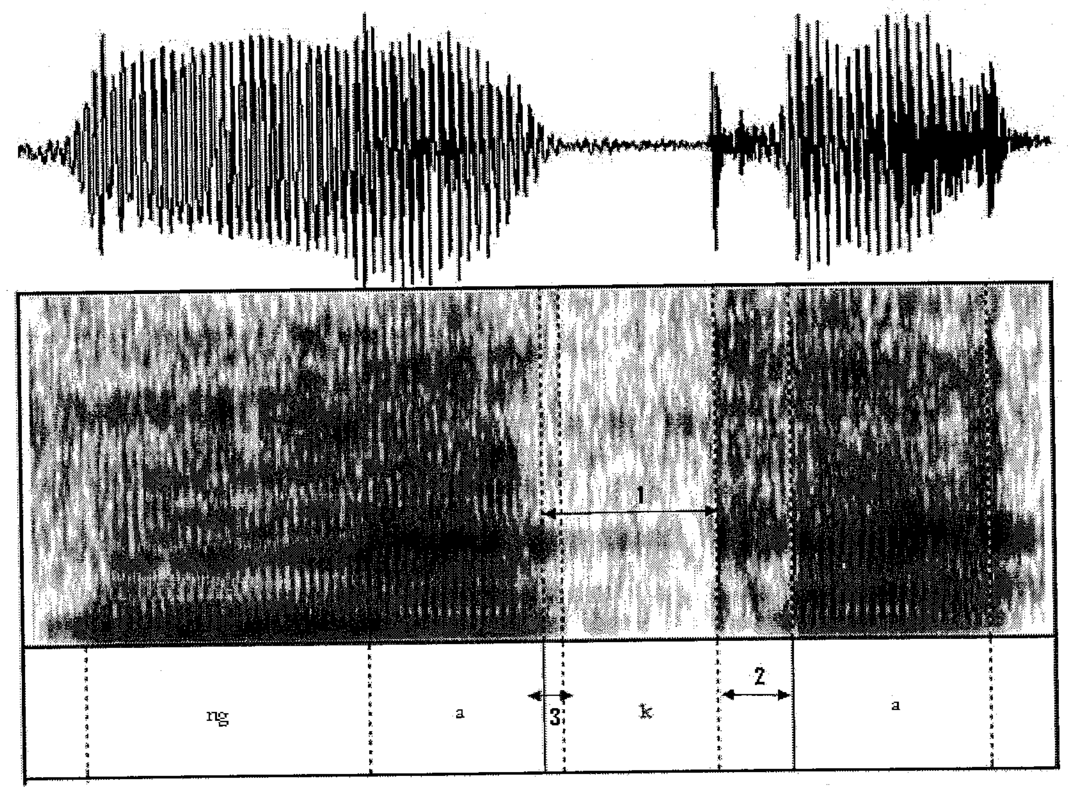

Figure 6. Example of stop-related measurements for Warlpiri *ngaka* 'later', modeled after Stoakes et al, 2007.

While the measurements of parameters like VOT and VTT in voiceless and partially voiced stop tokens were straightforward, two special types of tokens deserve special consideration. For the phonetically voiced stop tokens, the VOT is always negative, and the VTT is ill-defined, since the voicing

[3] VTT specifically measures what this work has been referring up to this point as the extent of "partial voicing" noted in Australian stops.

in a voiced stop is never supposed to "terminate." However, because a voiced stop can be approximated as a stop with the maximum VTT value, the VTT can thus be assumed out of convenience to be equal to the closure duration.

The phonetically spirantized allophones of stop tokens, because of their tendency to be voiced, were treated similarly to voiced stop tokens, although these fricative allophones have neither VOT nor VTT values. Spirantized allophones seemed to occur in all environments in free variation with the corresponding stops (in Yan-Nhangu the voiced stops in particular), although the voiced velar fricative [ɣ] was the most commonly observed across the languages studied. The notable exception in this discussion is in Kayardild, where no instances of spirantization were recorded. Table 5 summarizes the occurrences of fricative stop allophones in this study.

Bardi			**Warlpiri**			**Yan-Nhangu**		
Stop	# Tokens	% Tokens	Stop	# Tokens	% Tokens	Stop	# Tokens	% Tokens
p	4	10.8				*b*	2	9.5
t	3	13.0				*dh*	1	7.6
rt	1	15.8				*rd*	3	37.5
ty	3	5.6	*ty*	1	2.0	*dy*	3	17.0
k	17	45.9	*k*	13	25.0	*g*	9	56.2

Table 5. Occurrence of spirantized stop allophones (i.e. fricatives) in three languages studied.

3.0 RESULTS

3.1 Preliminary Investigation of Syllabic Position

Many of the stop tokens observed were in the post-stress C2 position, although a few were in C3 or other positions. This bias towards C2 position tokens was out of convenience, as it was easiest to find examples of stops and phonetic environments in C2 position. As a result, while it was not possible to explore in depth how much of a confounding role syllabic position played in all the languages studied in this work, it was at least feasible to look at the effect syllabic position may play in Warlpiri. After all, there were enough C2 and C3 tokens (primarily for /p/, /ty/, and /k/) to make preliminary observations on the effect of syllabic position on this study's dependent variables. VTT, VOT, and stop duration were all compared across C2/C3 positions in Warlpiri, as illustrated in Figures 7, 8, and 9. The overall clustered distribution of these values with respect to C2 and C3 show that the effect of C2 vs. C3 syllable position on the dependent variables was minimal at best, at least in Warlpiri. However, this result does not rule out the possibility of measurable effects in other syllabic positions, like the stressed C1 position.

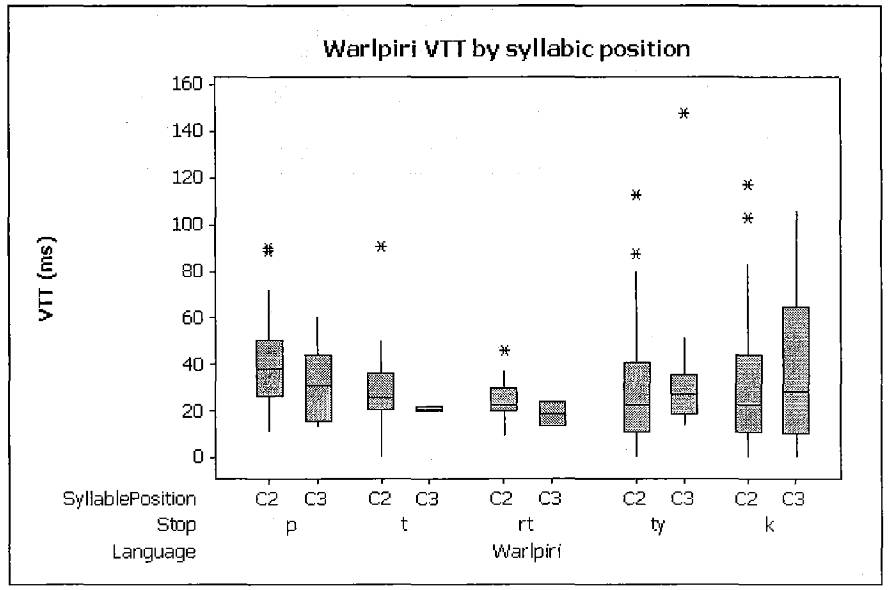

Figure 7. Boxplot of VTT values (ms) according to C2/C3 positions in Warlpiri

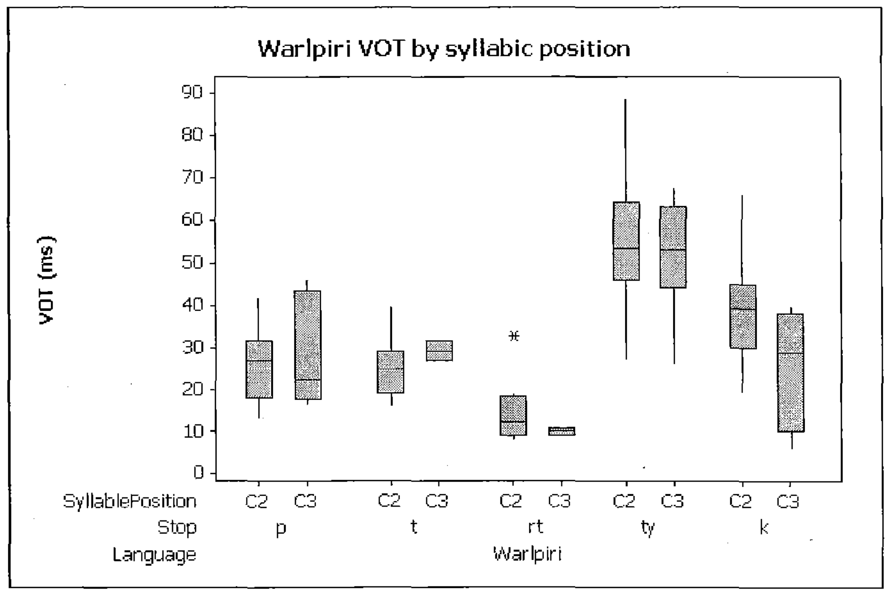

Figure 8. Boxplot of VOT values (ms) according to C2/C3 positions in Warlpiri

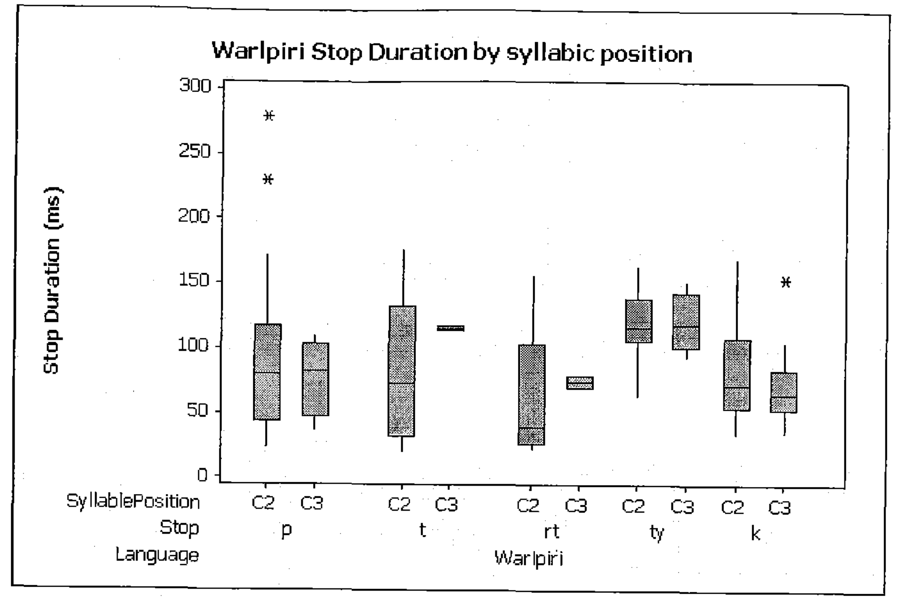

Figure 9. Boxplot of stop duration (ms) according to C2/C3 positions in Warlpiri

3.2 General Observations on Allophonic Voicing

In this study's analysis of allophonic voicing effects, the first step was to determine the voicing distribution of the tokens. Impressionistically, Bardi was remarkable in having nearly all of its tokens voiced in spite of the fact that Bardi had no phonological voicing contrast. In this way, Bardi patterned like other reported "voiced-stop" languages like Yidiny, Wambaya, and Yuwaalaraay (Hamilton 1996:54). Kayardild and Warlpiri, on the other hand, had a number of voiced allophones (about 40% of tokens), but were usually voiceless. In a language like Yan-Nhangu (YN), a language with a voicing contrast, there was a predictable distribution based on the contrast: the phonological voiceless stops were almost always phonetically voiceless, while the phonological voiced stops were almost always phonetically voiced. The numerical distribution is summarized in Table 6.

Token Count	Bardi	Kayardild	Warlpiri	YN (voiceless)	YN (voiced)
Voiced Tokens	123	47	77	1	78
Voiceless Tokens	10	84	103	123	4
Percentage Voiced Tokens	92.5%	35.9%	42.7%	0.0%	95.1%

Table 6. Tokens sorted by language and voicing parameter. For the sake of discussion, partially voiced stops are grouped with the other voiceless tokens.

3.2.1 Mean VTT duration across place of articulation

Mean VTT durations for voiceless stops seemed to vary according to language. For example, in Kayardild the average VTT value across all voiceless or partially voiced stops was around 60 ms, whereas Warlpiri and Yan-Nhangu's voiceless stops had average VTT durations of around 30 ms. The stops appeared to vary less as a function of place of articulation, however. This could suggest a common underlying process, like passive devoicing, that is active across all places of articulation which results in approximately consistent VTT averages, in a manner similar to the VTT averages occurring in Tiwi across place of articulation (Anderson & Maddieson 1994:143). In the case of Yan-Nhangu, which does contrast voiced and voiceless stops, the shorter average VTT duration (resulting in less partially voiced stops) might reflect the tendency for stops in this language to devoice sooner in order to make the voiced/voiceless contrast more salient. Table 7 summarizes the average VTT durations across the various places of articulation for Kayardild, Warlpiri, and Yan-Nhangu.

	Kayardild				Warlpiri				YN (voiceless series)		
	N	Avg	SD		N	Avg	SD		N	Avg	SD
p	30	65.04	32.74	*p*	40	38.61	19.52	*p*	28	31.82	24.16
th	25	65.06	23.03	*th*	-	-	-	*th*	22	25.41	19.04
t	19	75.28	38.27	*t*	34	27.82	15.85	*t*	12	43.00	25.47
rt	12	64.76	27.13	*rt*	20	24.43	8.47	*rt*	13	33.85	13.58
ty	22	65.06	31.19	*ty*	40	33.39	31.08	*ty*	16	29.94	18.47
k	34	63.06	32.74	*k*	52	31.20	28.74	k	33	16.02	13.25
Sum	142	63.95	30.03		186	31.92	24.15		124	27.53	20.55

Table 7. Average VTT durations (ms) across place of articulation from three Australian languages. Bardi and Yan-Nhangu's voiced stops are excluded because their mostly voiced stop tokens lack comparably defined VTT values.

If the passive devoicing model indeed applies to these stops, then it should be possible to predict the subtle effect of place of articulation on the duration of persistent voicing measured by VTT. After all, from the phonetic literature it is known that stops with constrictions in the back of the mouth, like a velar

/k/, are harder to keep voiced than stop segments formed in the front of the mouth, like bilabial /p/ (Hayes & Steriade 2004:13). Hence, one would predict that there would be a negative correlation between the backness of the stop constriction (from /p/ to /k/) and the average VTT duration.

In order to test this hypothesis, the Pearson's correlation was calculated for Kayardild, Warlpiri, and Yan-Nhangu's voiceless stops. While in Warlpiri and Yan-Nhangu a negative correlation was found (Walpiri r = -0.06, YN r = -0.24, compared with Kayardild r = 0.022), only in Yan-Nhangu did this correlation find statistical significance with $p < 0.05$ (YN p = 0.008). This lack of a negative correlation in Warlpiri was not surprising, given the outliers in VTT values across each place of articulation for Warlpiri as shown in Figure 10. If one compares the VTT distribution of Kayardild and Warlpiri with that of Yan-Nhangu (Figure 11), it becomes evident that by inspection that Yan-Nhangu's stops had a more defined downward sloping trend from /p/ to /k/ than either of the other two languages.

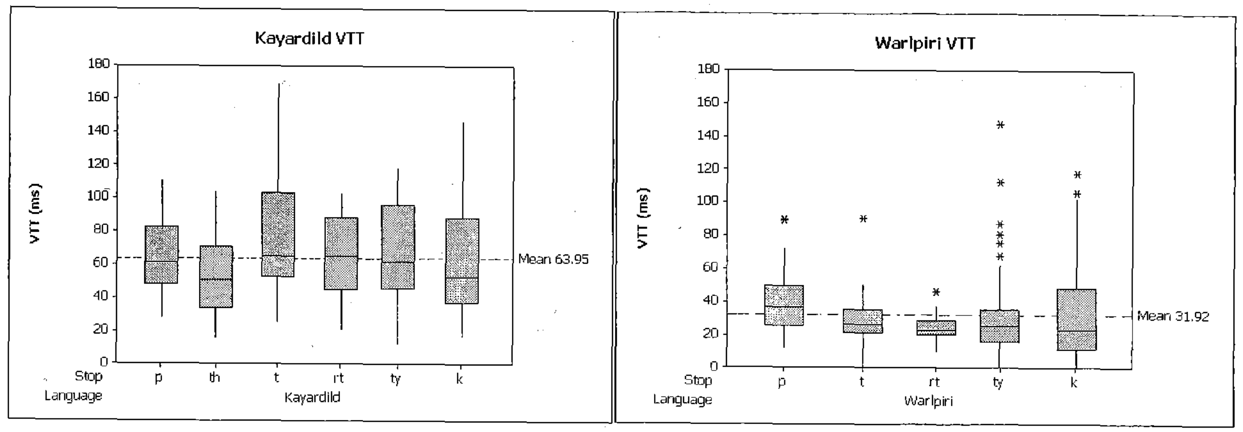

Figure 10. Boxplot of VTT (ms) according to place of articulation in Kayardild and Warlpiri.

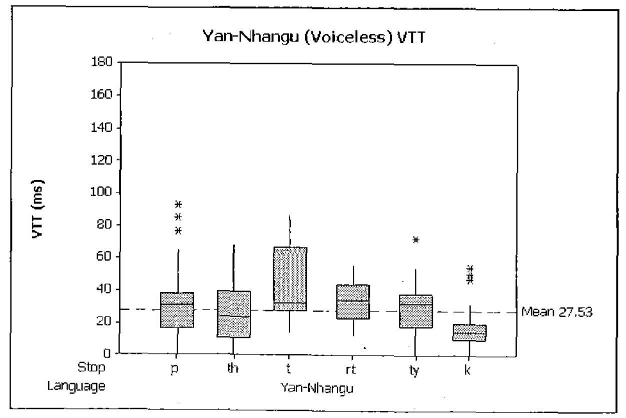

Figure 11. Boxplot of VTT (ms) according to place of articulation in Yan-Nhangu.

3.2.2 Mean VOT duration across place of articulation

Mean VOT values were more variable within the stop categories than across languages. On average, the mean VOT values for all stops across the languages studied in this work were on average around 30-40 ms (see Table 8). Within Warlpiri and Yan-Nhangu, the voiceless palatal stop (ty) was considerably aspirated with the longest VOT value, and the retroflex stop (rt) less so with the shortest VOT value (see Figure 12). These observations suggest that the placement of individual stops may in part be differentiated by VOT cues, although there were not enough tokens in the analyzable data set to establish any statistical significance in VOTs between all the stops.

	Kayardild				Warlpiri				YN (voiceless series)		
	N	Avg	SD		N	Avg	SD		N	Avg	SD
p	23	22.53	8.92	*p*	32	26.50	9.93	*p*	28	27.29	12.98
th	21	18.89	7.33	*th*	-	-	-	*th*	21	26.81	8.09
t	5	27.02	10.92	*t*	21	25.38	7.08	*t*	12	25.17	10.53
rt	2	31.50	7.78	*rt*	10	13.94	7.45	*rt*	13	16.31	11.51
ty	15	30.60	11.81	*ty*	33	53.36	14.47	*ty*	16	33.81	12.82
k	28	29.38	7.66	*k*	32	35.73	12.26	k	33	29.85	22.23
Sum	142	25.39	9.75		128	35.56	17.17		123	27.37	15.54

Table 8. Average VOT values for stops across place of articulation from three Australian languages, with the VOT values from Bardi and Yan-Nhangu's voiced stops again excluded, as well as any other voiced stops in the other three languages.

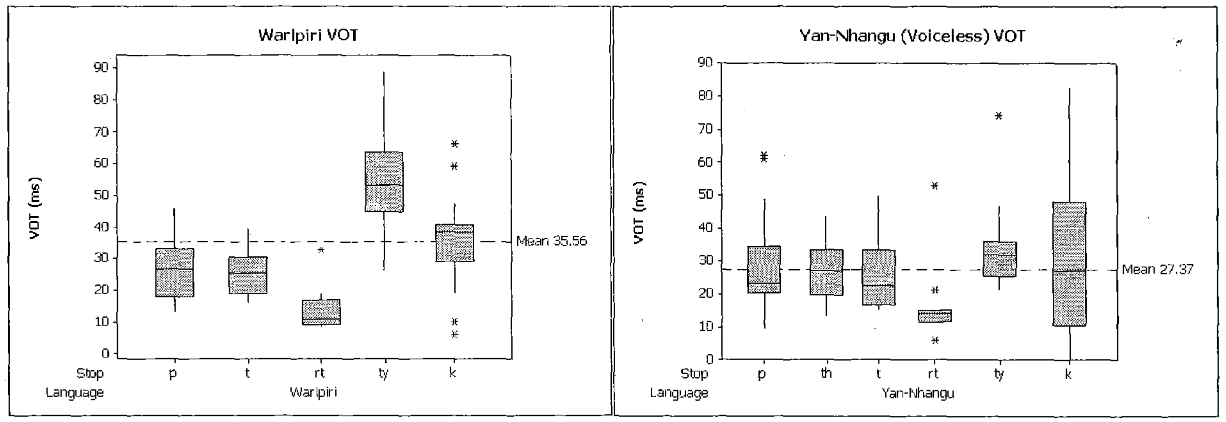

Figure 12. Boxplot of VOT (ms) for stops across place of articulation for Warlpiri and Yan-Nhangu. Note the difference in VOT distribution between the retroflex (rt) and palatal (ty) stops.

3.3 Averaged Durations: Models

While mean VOT and VTT measurements are certainly insightful, they do not summarize in isolation enough of the relevant phonetic context for the purposes of this work. Thus it was necessary to abstract away an "averaged stop" from the data combining the relevant mean measurements obtained in this study (see Figure 13). In particular, this work was interested in comparing the stops across languages for stop category and the nature of the preceding segment— vowel (V), liquid (L), rhotic (R), nasal (N). The average stops were generated for each of the individual languages studied and will be discussed in further detail. The parts of the average stop are be abbreviated as (1), (2), (3), and (4). For the purposes of discussion, average stop duration does not include the duration of the preceding segment.

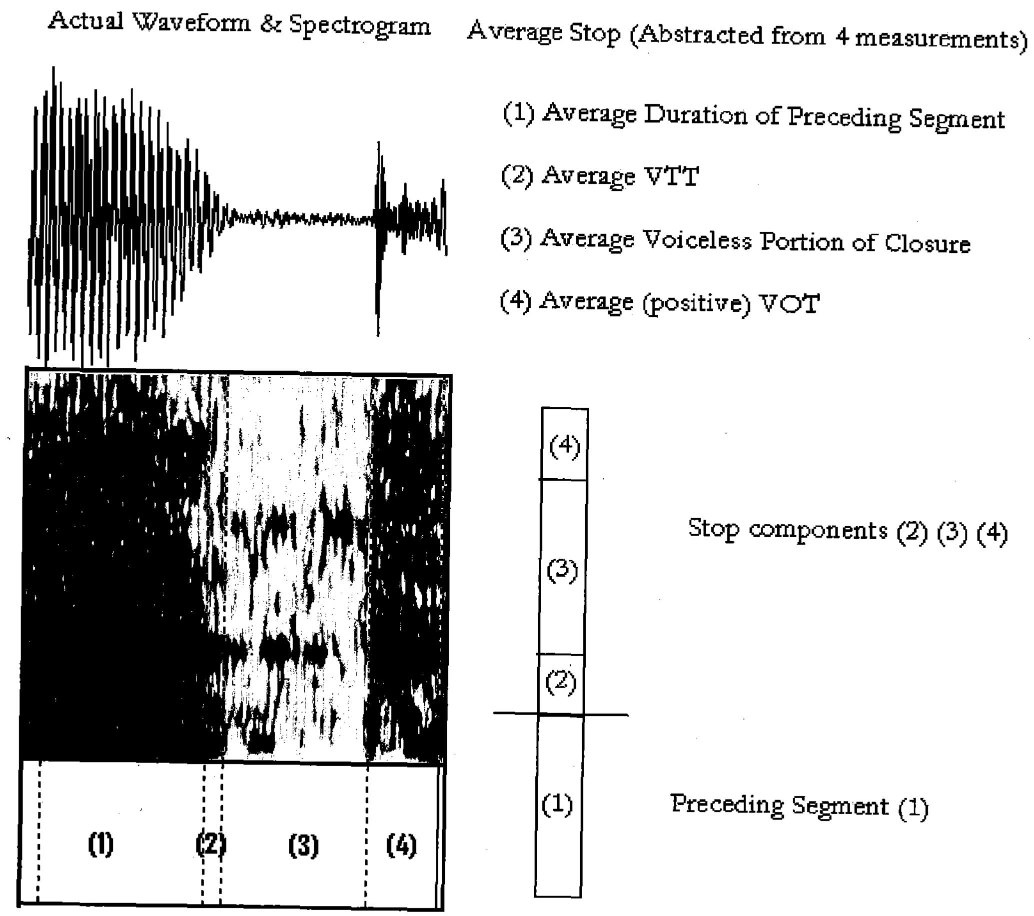

Figure 13. Mean measurements abstracted from the stop and its immediate environment (preceding segment). The average VOT in this model is not represented here if it is negative.

3.2.1 Bardi

In Bardi, a language with its stops typically phonetically voiced, it was expected that its (3) and (4) values contributed little to the averaged stop, and that the stop would consist solely of persistent voicing duration (VTT), which for voiced stops was defined as equal to the closure duration. This is what was in fact generated in Figure 14. An interesting pattern also emerges in Bardi: the duration of the stop seemed to be systematically correlated with the sonority of the preceding segment. For example, regardless of place of articulation, stops preceded by the more sonorous vowel appeared to be longer in duration than liquids (laterals and rhotics) which in turn are longer than stops preceded by nasals. This trend did not apply only to Bardi but to other languages as well. The durations of the average stops ranged anywhere from about 25 to 125 ms depending on place of articulation and preceding segment.

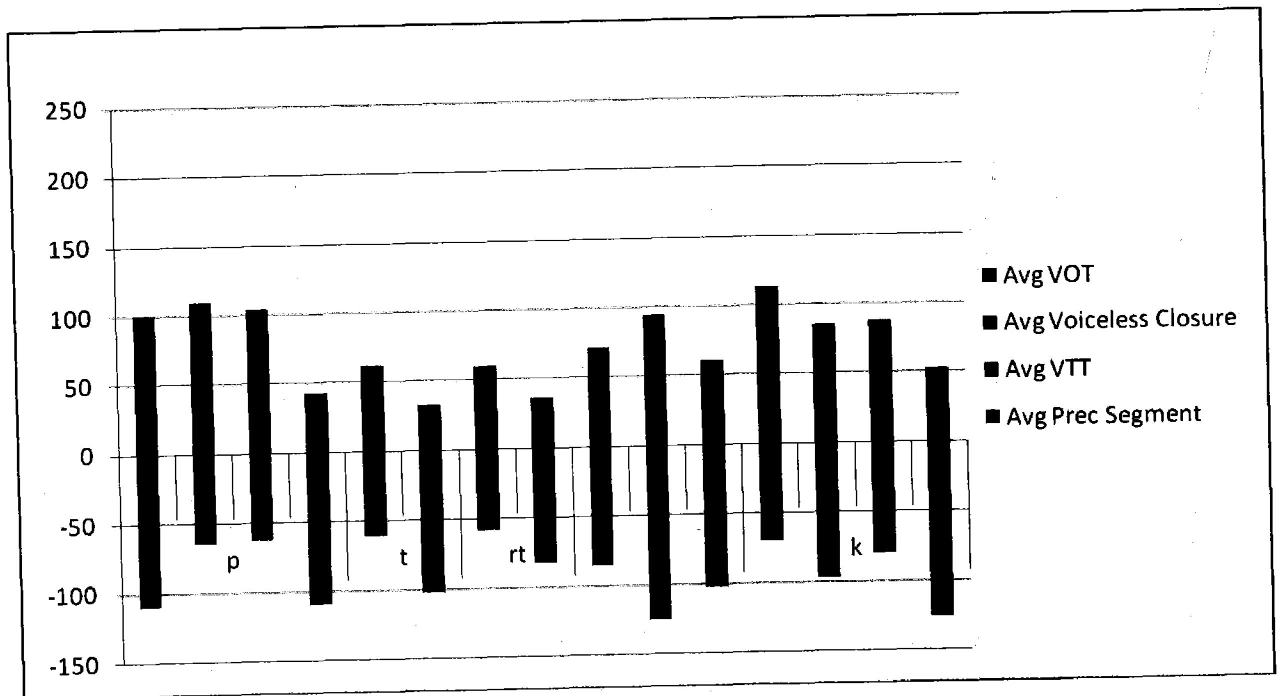

Figure 14. Average stop duration for Bardi (ms). The tokens with preceding segments as long vowels were excluded from the average stop analysis.

3.2.2 Kayardild

Kayardild, the averaged stops of which in general appeared to be longer in duration and less voiced than that of Bardi (range approximately from 50 to 175 ms), showed higher portions of the average

stop consisting of a voiceless segment (3) and positive VOT (4) duration. Like in Bardi, stops that were preceded by the more sonorous vowel tended to be longer than those preceded by liquids which were in turn longer than those preceded by nasals. Perhaps as a natural consequence of this correlation between preceding segment sonority and duration did stops in nasal-stop clusters tend to be more voiced than in other environments, as has been observed by Hamilton (1996: 54). After all, if one assumes a relatively constant VTT value across all stops due to the mechanics of passive devoicing, and the stop is relatively shorter in a nasal-stop cluster, it is likely ceteris paribus that residual voicing would persist through the stop than in the case of a longer stop (Ladefoged & Maddieson 1996:53).

One interesting pattern in Kayardild was the tendency for many apical clusters[4] to have a trilled release (Round p.c.). For example, for the Kayardild word token *kultu* 'flank,' the liquid-stop cluster was pronounced somewhat like [kuld^{r}u]. This trilled release posed methodological problems to the stop duration labeling process, since the trilled release would occupy the place of the normal aspirated VOT segment (4) of a typical stop and was thus coded for such in the average stops, although it is unclear

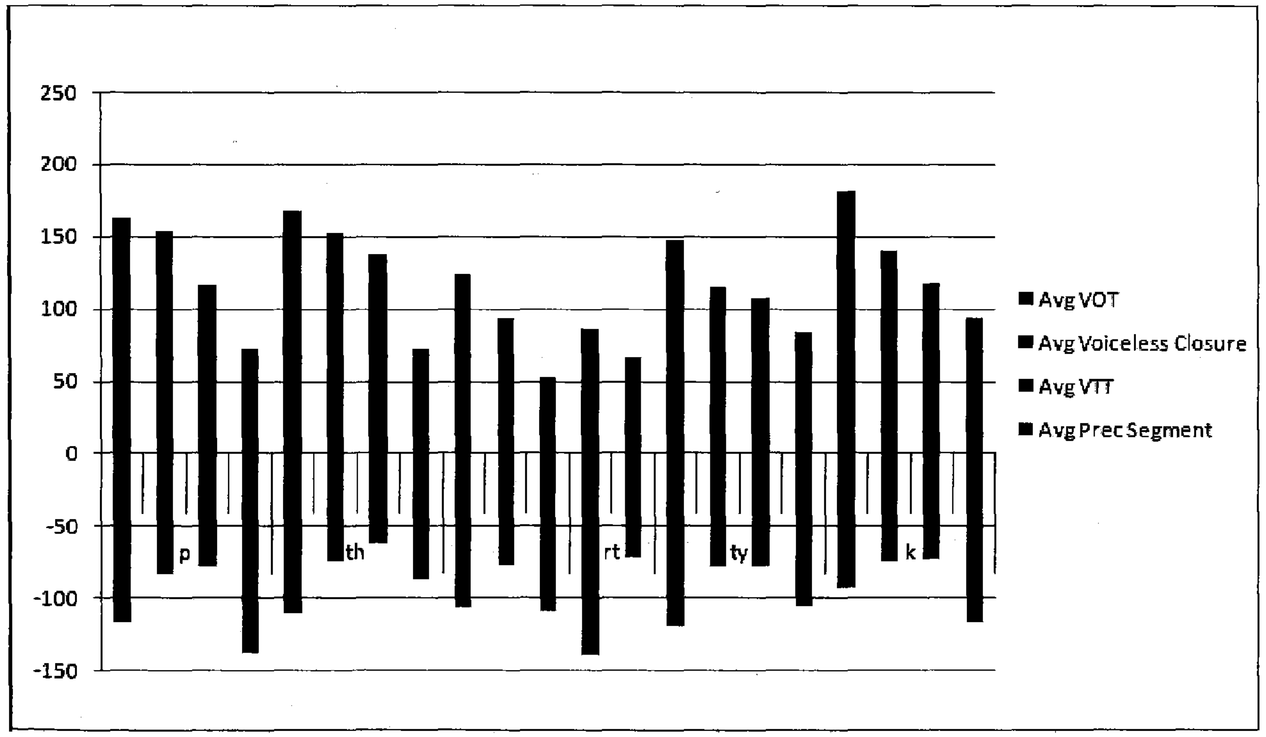

Figure 15. Average stops for Kayardild.

[4] Apical clusters are defined here as consonant clusters with an apical stop (i.e. alveolar /t/ or retroflex /rt/)

whether this secondary articulation should be considered a proper part of the stop.

3.2.3 *Warlpiri*

Warlpiri patterned mostly like Kayardild in terms of the aforementioned sonority trend in the preceding segment and in particular the trend for stops in nasal-stop clusters to be shorter and completely voiced compared to other environments. Warlpiri also appeared to have a greater variation in stop duration than in Bardi or Kayardild, with average stop duration in Warlpiri ranging from 25-175 ms according to preceding segment and place of articulation. Like in Kayardild, the longer stops tended to be voiceless or partially voiced, while the shorter stops (especially in nasal-stop clusters) tended to be voiced throughout their duration.

One pattern that seemed to be unique to Warlpiri is the degree of aspiration, measured by VOT, found in the palatal stop /ty/ in all environments. Comparison of Figure 16's palatal stops with those of other languages shows that VOT forms a major contribution to the average stop duration (50 ms or more) in Warlpiri palatals. Given that the notable palatal stop aspiration seems to only be found in Warlpiri, this could simply reflect a language-specific property of Warlpiri palatals.

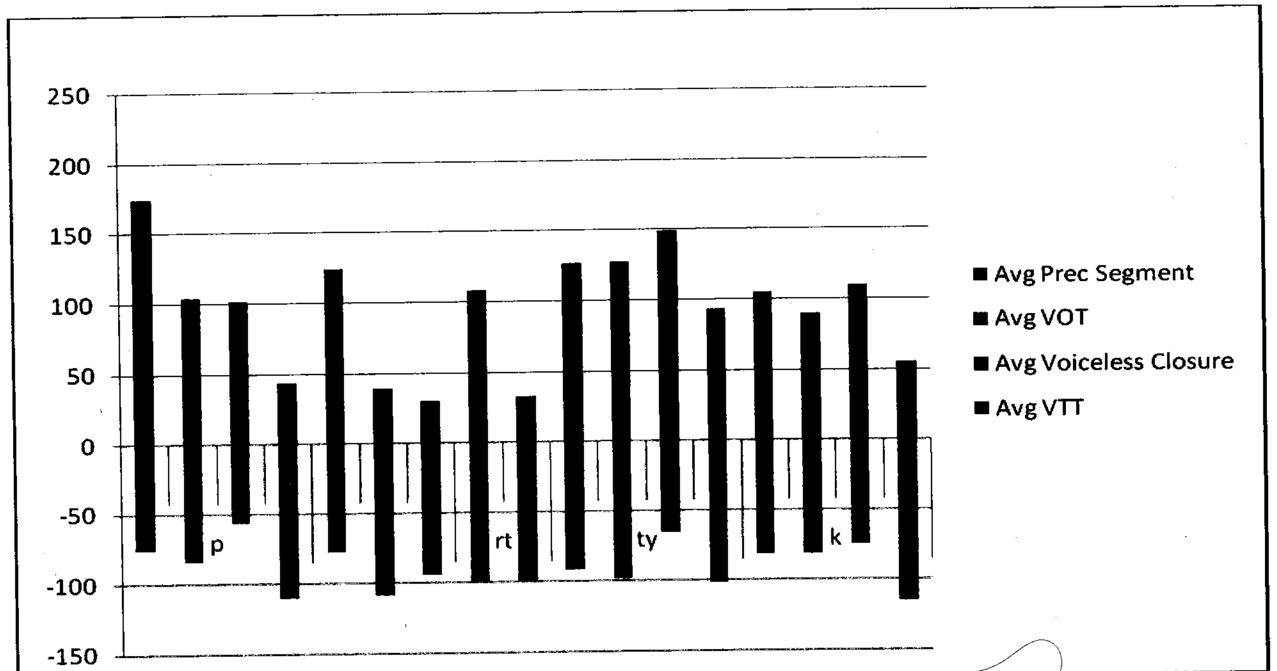

Figure 16. Average stops for Warlpiri.

3.2.4 Yan-Nhangu

The Yan-Nhangu voiced stop series, shown in Figure 17, patterned much like the Bardi voiced stop series with stops that are nearly completely voiced. The average duration for Yan-Nhangu voiced stops ranged approximately from 30 to 100 ms, and are on average shorter in duration than those of Kayardild (Figure 15), Warlpiri (Figure 16), or even the Yan-Nhangu voiceless stop series (Figure 18).

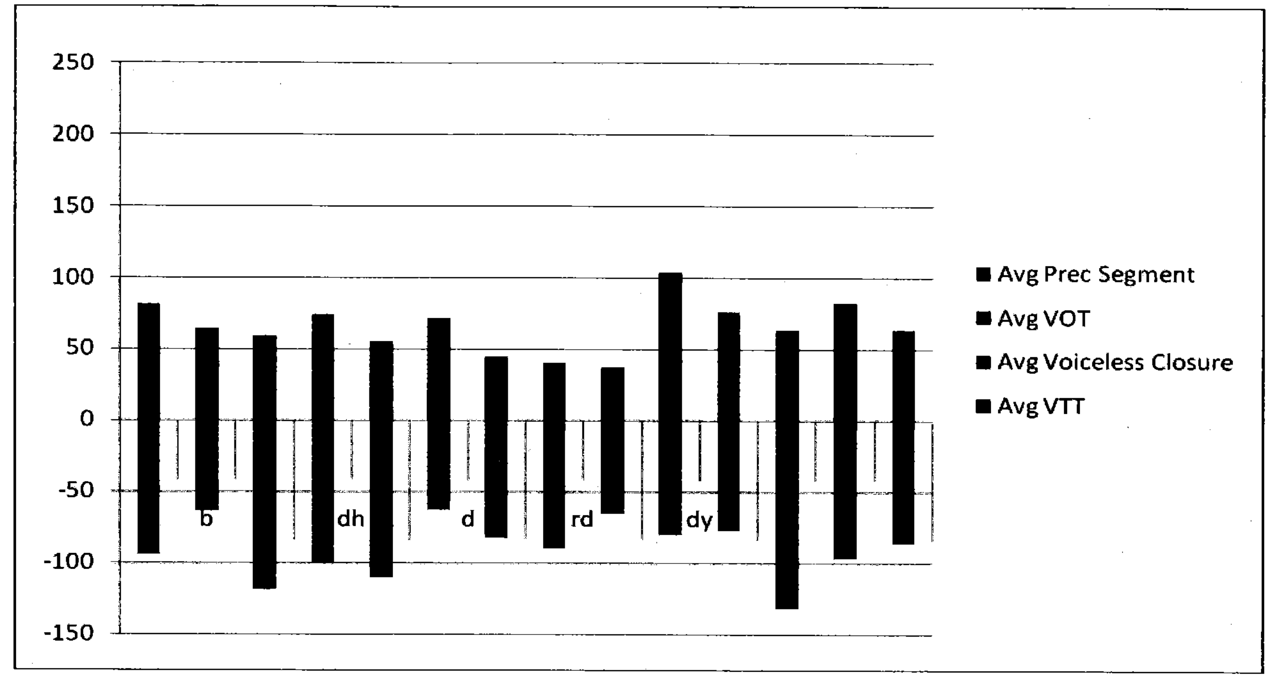

Figure 17. Average stops for Yan-Nhangu (specifically its voiced series).

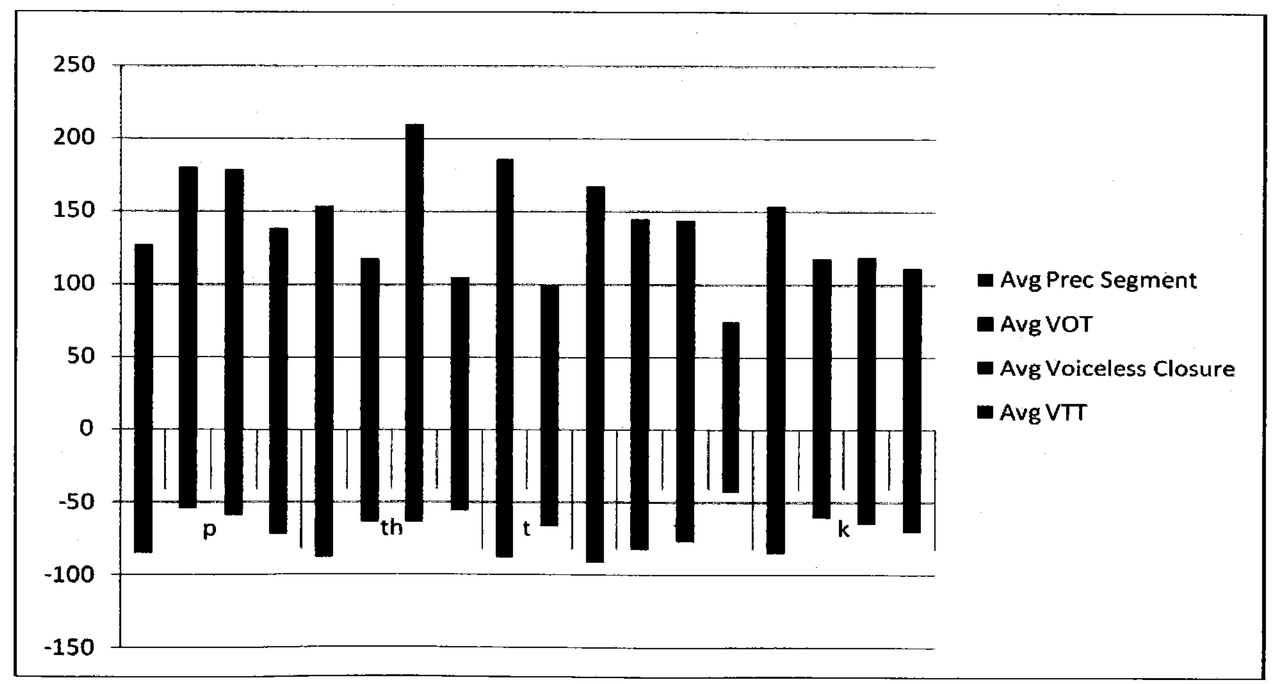

Figure 18. Average stops for Yan-Nhangu (specifically its voiceless series).

The Yan-Nhangu voiceless stop series, shown in Figure 18, consisted primarily of phonetically voiceless and partially voiced stops. While this observation was not remarkable in itself, it is interesting to also observe that the voiceless stops were on average considerably longer than their voiced counterparts, with the nasal-stop clusters again appearing to have the shortest stop durations on average. The average duration for Yan-Nhangu voiceless stops ranged from 75-200 ms, whereas the voiced stops only ranged from 30-100 ms (about half the duration of the voiceless stop). This durational difference was reminiscent of Evans & Merlan (2004) observations in Jawoyn, where the voicing contrast appears to be accompanied by a general length contrast that may be phonological as well. While it may be tempting to analyze the Yan-Nhangu voiceless stops in a similar way, as phonologically geminate versions of the "voiced" series, the phonotactics of Yan-Nhangu appear to disfavor such an interpretation (Bowern p.c.).

3.4 Post-Hoc Tests: Stop Duration and Preceding Segment

Several general observations were made about the average stops in the previous section. One of the stronger trends that recurred throughout the four languages studied concerned the effects of the preceding segment's sonority on the average stop duration. In particular, stops preceded by nasals in a nasal-stop cluster—regardless of place of articulation— were generally shorter than stops preceded by vowels. In order to determine whether this trend was statistically significant, several post-hoc analyses were performed. One-factor ANOVA tests performed individually on these languages showed that the effect of preceding segment category on stop duration was highly significant in Bardi ($F[3,129]=24.17$, $p < 0.0001$), Kayardild ($F[3,138]=35.72$, $p < 0.0001$), Warlpiri ($F[3,180]=78.92$, $p< 0.0001$), and Yan-Nhangu's voiceless series ($F[3,120]=4.44$, $p= 0.005$). In contrast, the effect was not shown to be significant at the $p< 0.05$ level for Yan-Nhangu's voiced series ($F[3,77]=2.13$, $p= 0.104$). In post-hoc paired comparisons of means on the applicable data, preceding nasals had stop durations that were distinguishably shorter at the 95% significance level than preceding vowel categories. In addition, Kayardild had durations of stops preceding liquids distinguishably shorter than that of those preceding vowels and longer than that of those preceding nasals, again at the 95% significance level.

These post-hoc analyses appear to confirm the observation that in the languages studied, the stops preceded by nasals were shorter than stops preceded by vowels. It is unclear why this may be the case, although the differences in stop duration among different preceding segment categories could in turn affect the allophonic voicing distribution of stops according to preceding segment. After all, if stops in nasal-stop clusters are significantly shorter than stops in other environments in Australian languages, and shorter stops tend to be easier to keep voiced according passive devoicing model, then one should expect stops in nasal-stop clusters to be largely voiced, an observation which the data from the languages in this study appeared to support.

4.0 DISCUSSION

Several hypotheses were outlined in this study explaining how allophonic voicing could arise. The simplest hypothesis, after one has of course ruled out any phonological voicing contrast, is to assume that allophonic voicing is explained by free variation in all its forms— from different speakers, from different elicitation contexts, and so on. In this study, the possibility of free variation inherent in having different speakers provide tokens being responsible for some allophonic voicing effects was examined. However, based on the investigation of data from three Warlpiri speakers, it was shown that these speakers' productions of stops largely agreed with each other in the relevant respects.

While the free variation model is still plausible in explaining some of the allophonic voicing effects evident among the variety of language communities in Australia, free variation also has its problems. For instance, it fails to predict the regular linguistic patterns and allophonic distributions that are observed across these languages, such as the intuition that nasal-stop clusters in Australian languages tend to have voiced stops (Hamilton 1996:54). In addition, evidence from this study demonstrates that allophonic voicing is not simply free variation. After all, regularities in the data, like the observation that longer stops tended to be less voiced, seem to confirm that allophonic voicing is not insensitive to the stop's greater phonetic context.

The next approach to examining allophonic voicing is a quasi-phonological one: to assume an underlying form to the stop (normative articulation model) or not (underspecification model) that is given either [+voice] or [-voice] values in different environments. The major problem with this approach, as this study demonstrates, is that Australian stops, especially in languages that do not contrast for voicing, phonetically appear as various degrees of "partially voiced" that do not necessarily obey the tight rules of phonology like [+stop] → [+voice] / V_V. This problem is to be expected, since one cannot use the language of phonology to deal with effects, like allophonic voicing, that are by definition outside the phonological system.

The most promising approach to explaining allophonic voicing in Australian languages, then, is to posit that stop realizations are contextually conditioned to some degree by phonetic factors like stress and stop duration. This work's investigation on segments' preceding stops support the validity of this phonetically-grounded model, at least as far as confirming that factors like the preceding segment and stop duration can affect allophonic voicing tendencies.

4.1 Reconsidering the Passive Devoicing Model

It is likely that given the trends observed in the averaged stops in section 3, the biggest predictor of whether a stop is phonetically realized as voiced, voiceless, or somewhere in between is the length of the stop. The idea that a stop's length can affect the maintenance of its voicing is not theoretically unfounded. After all, the phonetic literature discusses at least two universal sources of articulatory difficulty in maintaining stop voicing: the overall length of oral closure and size of the cavity behind the closure as determined by place of articulation (Hayes & Steriade 2004:13). The difference between maintaining voicing in the case of a [g] versus a [b] is the relatively small volume of air behind the velar closure in the case of [g] that causes it to spontaneously devoice after enough air passes through the vocal cords that the air pressure differential that normally maintains voicing is insufficient. In the case of geminates, where the oral closure is lengthened, the possibility of passive devoicing is increased because the pressure differential necessary for voicing can only be maintained for so long (see Ladefoged &

Maddieson 1996). Thus, by the overall articulatory constraints presented here, one can already generate a hierarchy of stops that respond differently to passive devoicing that naturally occurs in Australian languages. A longer (perhaps even phonologically geminate) velar stop is perhaps the hardest to keep voiced throughout its entire duration, whereas on the other extreme a shorter or non-geminate bilabial stop is perhaps the easiest to keep voiced by passive devoicing (Hayes & Steriade 2004:13).

While a geminate/non-geminate analysis does not apply to any of the tokens gathered in this study, the more general principle that stop duration can affect its voicing does. A possible analysis of the Australian languages like Bardi, then, could be that the typically voiced realization of its stops is a natural phonetic consequence of how typically short the total duration of the stops are compared to that of Warlpiri or to a lesser extent Kayardild. After all, the average stop duration across all stop categories for Bardi is about 70 ms, compared to Warlpiri's average of 120 ms or Kayardild's average of 90 ms. One thus need neither to appeal to the argument that Bardi and other "voiced-stop" languages must have voiced stops as their normative articulation, nor to the argument that Kayardild and Warlpiri have typically voiceless stops. Instead, if the passive devoicing model is true, one should be able to predict how voiced the language's stops tend to be realized from average stop durations alone.

It is remarkable that Australian languages like Yan-Nhangu and Tiwi, which contrast for voicing, also appear to obey the same passive devoicing principles that languages without a voicing contrast do. In both these languages, after all, longer stops are usually nearly voiceless, and shorter stops are usually voiced, just like the passive devoicing model would predict if they did not have a voicing contrast. It is unclear why this pattern should occur, but it is certainly worthy of further investigation.

4.2 Directions for Further Research

It is clear that while cross-language comparisons are insightful in determining the range of allophonic voicing effects in Australian languages, the four languages studied in this work do not begin to exhaust the range of the phonetic and phonological variation across Aboriginal Australia and its speakers. While it is hoped that the generalizations on allophonic voicing that are consistent with the passive devoicing model apply beyond the four languages in question, such generalizations remain tentative until more acoustic data from these four languages— as well as from other Australian languages— is gathered and analyzed. In addition, it is hoped that future studies involve many more speakers, as the natural variation between speakers can hardly be assessed on three Warlpiri speakers alone. Nevertheless the preliminary cross-linguistic data represent a step in the right direction towards understanding the possible phonetic constraints on allophonic voicing amid the natural free variation inherent in these Australian languages.

Other phonetic constraints in allophonic voicing remain subject to future research. For example, the potential variable of stress and position was never fully explored in this work. While there was some preliminary work determining the potential effect of C2 and C3 position on the dependent variables explored in the work, the particular emphasis on the C2 syllabic position leaves little said about the stop voicing effects and constraints that might appear word initially or word finally.

5.0 CONCLUSION

This present work has addressed a much understudied phenomenon in Australian Aboriginal languages: allophonic voicing in stops. Allophonic voicing effects are especially observable in Australian languages with only one stop series, where voiced and voiceless instances of stops appear interchangeable on the phonetic level. However, upon further investigation, it is clear that the stops in these Australian languages show more variation in voicing than just voiced and unvoiced stop variants, as many stops can be phonetically described as more or less partially voiced. Thus, it perhaps makes more sense to view allophonic stop voicing on a continuum, measured by VTT durations, for instance, rather than be constrained to the language of phonology and use artificial [±voice] labels.

The underlying theory behind allophonic voicing is to date not well understood, and a lot of phonetic groundwork and analysis still needs to be done on Australian languages in order to find the right theory. Nevertheless, one of the contending explanations behind allophonic voicing lies in the passive devoicing model. In this model, since stops in Australian languages are produced with no actual

laryngeal opening gesture, the voicing from the previous voiced segment, like a vowel, can passively be passively maintained well into the start of the stop. This model not only can account for the degrees of partial voicing observed in Australian language data, but can also make powerful predictions on the distribution of voiced, voiceless, and partially voiced allophones that is observed in Australian languages according to phonetic constraints. For example, one prediction that the passive devoicing model makes is that because it is harder to maintain voicing through longer stops, longer stops would be less likely to show more voicing and thus have smaller VTT measurements. This prediction appears to be largely confirmed across the four Australian languages studied in this work.

In the larger picture, if the passive devoicing model proves to be the correct explanation behind allophonic voicing in Australian languages, then this gives further credence to the idea that allophonic voicing effects, particularly in Australian languages, are not outside the methods of rigorous phonetic analysis. It is hoped that more acoustic studies on Australian field tapes and recordings, a number of which remain largely unanalyzed, can be analyzed in this fashion in the future.

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