

An Acoustic and Aerodynamic Analysis of Consonant Articulation in Bininj Gun-wok

Hywel Martin Stoakes

December, 2013

Submitted in total fulfilment of
the requirements of the degree of
Doctor of Philosophy,
Produced on archival quality paper.

**The School of Languages and Linguistics,
The Faculty of Arts,
The University of Melbourne.**

WARNING: Aboriginal and Torres Strait Islander readers are warned that this work may contain the images or names of deceased persons.

This manuscript is produced on archival quality, acid-free paper.

Set in Charis SIL, 11pt,
and Hasklig Light, 11pt
distributed under the SIL Open Font License Version 1.1.
<http://scripts.sil.org/OFL>
Originally formatted for $\text{\LaTeX}$ in Scrivener
via MultiMarkdown using the Memoir class.

Hywel Martin Stoakes, 2014



(CC BY-NC-ND 4.0)

<http://creativecommons.org/licenses/by-nc-nd/4.0/>

Abstract

This thesis is an acoustic and physiological phonetic analysis of the consonant system in Bininj Gun-wok (BGW), an Australian language spoken in North Western Arnhem Land.

The primary aim of this thesis is to provide a detailed phonetic description of an Australian language looking at the articulation of intervocalic stops and nasals. This investigation examines a number of phonological contrasts in the language that have not had prior phonetic investigation. The analysis is divided into three experiments, the first two of which focus on differences in length and strength between stop series in BGW. The third experiment examines patterns of coarticulation within nasals. The materials used consist of two corpora with a total of 24 first language speakers of BGW. Corpus I includes five speakers of the Kuninjku variety and Corpus II includes 19 speakers of the Kunwinjku variety, all recorded under field conditions in Western Arnhem Land. Corpus I is made up of acoustic recordings and Corpus II, physiological recordings with associated time-aligned audio.

An important phonological feature of BGW is a two stop series that contrasts for length. The two stops in the series, which are all matched for place of articulation, are phonologically classed as lenis or fortis. The primary focus of this study is to determine the phonetic realisations of these stop categories. The secondary focus of this study is to examine patterns of coarticulation between nasals and stops in BGW, as nasalisation can mask the acoustic cues that are needed to perceive place of articulation.

Earlier cross-linguistic studies have consistently shown that duration is a key difference between stop categories within a language. This is particularly for languages that do not use voicing as a cue to the contrast. In the current study, acoustic analysis is used to measure duration and for analyses of burst characteristics of BGW stops. An articulatory analysis investigates differences in strength and also the prevalence and timing of voicing between the stop series. Findings show that there is a clear durational difference between lenis and fortis stops. Voice onset time differences are dependent on place of articulation rather than reliably signalling between stop categories. In addition there is a clear difference in strength in terms of peak intra-oral pressure.

In the study, medial homorganic articulations are separated into three categories termed lenis, fortis and geminated consonants. These represent short intra-morphemic stops, long intra-morphemic stops and long inter-morphemic stops respectively. Fortis stops and geminates clusters do not differ in terms of duration. There are however measurable differences between them including pressure impulse—pressure measured over time—showing that duration and pressure are independent. The timing of pressure peak is similar for lenis and fortis stops is similar, yet geminates show a delay in the intra-oral pressure peak.

Across languages, anticipatory nasalisation is thought to be under direct control of the speaker. Carry-over nasalisation in contrast has proven to be a result of bio-mechanical inertia. The secondary focus of this thesis is an examination of nasalisation and directionality of nasal assimilation in BGW as well as the durational aspects of nasals in clusters. Aerodynamic results show that the rise of the nasal airflow, in medial nasals, is delayed to be almost coincident with the oral occlusion. The inference is that the

velum is closed during the preceding vowel and opens quickly at the onset of the nasal. In a cluster of nasals followed by a stop, the nasal has a greater duration than the stop. In clusters of stops followed by nasals, it is the stop that has the greater duration. This suggests strengthening in a medial position.

The post-tonic medial position is prosodically eminent, as this is where the majority of phonetic contrasts are found for Bininj Gun-wok and Australian languages in general. This investigation into medial consonants in BGW represents the first major phonetic investigation into stop articulation in an Australian language and provides key support for this proposition.

KEY WORDS: phonetics, phonology, speech production, aerodynamics, Australian Aboriginal language

Declaration

This is to certify that:

- (i) The thesis comprises only my original work towards the PhD,
- (ii) Due acknowledgement has been made in the text to all other material used,
- (iii) The thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

Signed,

Hywel Stoakes,
(10th September, 2014)

Acknowledgements

Firstly, my deepest thanks go to my academic supervisors, Janet Fletcher and Andy Butcher for their guidance and patience. I also thank Nick Evans for igniting enthusiasm for language and imparting a small portion of his knowledge of Bininj Gun-wok. Murray Garde for furthering my understanding of cross-cultural communication. Thanks for your organising of community access and introducing me to the people of Mamardawerre. Most importantly, *Ngamanjbom* (my enduring gratitude) to the generous and patient people of Mamardawerre, particularly Conrad Maralngurra and Rosemary Nabulwad. Geoff for the buffalo and the driving. Thanks to all of my *Yabok*: Especially Margaret, Janice, Molly, Doreen, Old Stephanie, Marlene, Jill who each gently pushed me in the right direction. *Kokok* who changed how I see the land. My *Kakkali*, Wudip who guided me with his incredible eyesight and Isaiah Burrunali. Thanks especially go to the *wurdurdwurd* (children) who patiently taught me the most language of all. The staff at Injalak Arts centre in Kunbarllanjnja when I first crossed into Arnhem Land, Anthony Murphy, Rebecca Say, Andrew Sinclair and Gabriel Maralngurra. Esther Djayhurmga. The representatives for the traditional owners of Kunbarllanjnja, Donald Gumurdul and Jacob Nayinggul. My thanks go to the Northern Land council for arranging permits and the staff at NARU, ANU: Especially Helen, Andrew, and Lyle, for vehicle and equipment hire. My colleagues at the University of Melbourne, Mary Stevens and Debbie Loakes who I cannot thank enough for the support and motivation as well as tea and thoughtful discussion. Thanks for the editing Deb. My thanks go to Marija Tabain, Nicola Piper, Bruce Birch, Nick Thieberger, Rachel Nordlinger, Ruth Singer, Alice Gaby, Brett Baker, Rikki Bundgaard-Neilsen, Mark Harvey, John Hajek. Lesley Stirling, Erich Round, Ian Green, Isabel O'Keeffe, Judith Bishop, Sebastian Fedden, John Henderson and Alan Dench who have all had influence on the direction of this thesis at various stages of its long gestation. My colleagues in the Phonetics Laboratory at the University of Melbourne, past and present: Debbie and Mary, Colleen Holt, Bella Ross, Amos Teo, Olga Maxwell, Tom Harris, Simone Graetzer, Hilmi Hamzah, Rosey Billington, Joshua Clothier, Eleanor Lewis and our compatriots in the field-work lab. Gavin Nebauer for technical support and conversations about sound recording in general. Bob Evans for relating some of his teaching and language experiences in Western Arnhem Land to me. Jonathan Harrington, Steve Cassidy, Tina Johns and Lasse Bombian for their efforts in developing and maintaining the Emu Speech Database. Christel Butcher for making me feel so welcome on my visits to Adelaide. JVT for sharing his office with me in the drawn-out final stages. Last but not least my wonderful family: Alice for her love, friendship, support and spectacular proofreading skills, our children Ffion and Anwen for being a constant inspiration and a welcome diversion. My Mum, Marie, and Dad, Cris, for giving me such inspiring experiences growing up and feeding my passion for knowledge, Dad: thanks for the maps and editing. Michele for being the world's best *kurrung* and thanks to Don for coaxing me back into academia. Lucy, Jeremy, Sister Elizabeth and the nuns of S. Maria del Carmine al Morrocco, Tavernelle. To my friends in Castlemaine and on the Bellarine, thank you for diverting my attention with music, food and a thoughtful ear. Thanks also to all the professional staff in the Linguistics Department over the years. This research was made possible by grants from The University of Melbourne (Fieldwork fund, MATS PORES), a Studentship from the linguistics department and funding from an Australian Research Council grant (DP0557540) awarded to Janet Fletcher and Andrew Butcher.

Contents

Contents	ix
List of Figures	xiii
List of Tables	xix
1 Introduction	1
1.1 Biniŋ Gun-wok: people and language	4
1.2 Previous linguistic research on Biniŋ Gun-wok	8
1.3 The phonology of Biniŋ Gun-wok	10
1.3.1 Vowels	16
1.3.2 Phonotactics	18
1.3.3 Two stop series in Biniŋ Gun-wok	22
1.4 Previous phonetic studies in Australian languages	27
1.5 Hypotheses and research questions	31
1.6 Organisation of the thesis	31
2 Consonants: length, strength and voicing	33
2.1 Fortis and lenis	33
2.1.1 A cross-linguistic survey of lenis and fortis	36
2.1.2 Experimental Research	39
2.2 Geminates	41
2.3 Voice onset time	46
2.4 Voicing, aerodynamics and laryngeal tension	50
2.4.1 Analyses of voicing patterns	53
2.4.2 Voicing and devoicing	54
3 Nasals and coarticulation	57
3.1 Place of articulation cues in nasals	59
3.1.1 Spectral properties of nasals	60
3.1.2 Aerodynamics in nasals	61
3.1.3 Vowel height and nasalisation	62
3.2 Coarticulation and assimilation	63
3.2.1 Models of coarticulation	64
3.2.2 Coarticulation resistance	66
3.2.3 Locus equations	67
3.2.4 Nasal assimilation and coarticulation	69

4	Australian languages and medial consonant articulation	71
4.1	The stop contrast: Australia	72
4.1.1	Experimental research: Australia	78
4.1.2	The stop controversy	81
4.1.3	Fricatives in Australian languages	84
4.2	Nasals in Australian languages	86
4.3	The place of articulation imperative and the medial position	87
4.4	The phonetics of consonants in Bininj Gun-Wok	92
4.4.1	Peripherals	93
4.4.2	Coronals	95
4.4.3	The glottal stop	98
4.5	Aims, hypotheses and research questions	99
5	General method and statistical tools	105
5.1	Linguistic material	106
5.2	Speakers	108
5.2.1	The word lists	111
5.3	The recording method	114
5.4	Analysis	115
5.4.1	Labelling and segmentation	116
5.4.2	The annotation criteria	116
5.5	Statistics	121
5.5.1	Linear mixed effects models	121
5.6	The acoustic method	122
5.6.1	Materials	124
5.6.2	Queries	127
5.6.3	Measuring consonant duration	127
5.6.4	Voice onset time	127
5.6.5	Voice termination time	128
5.6.6	Vowel duration and vowel to consonant ratio	129
5.6.7	Analysis of burst amplitude	131
5.6.8	Spectral analysis	131
5.6.9	Locus equations	131
5.7	The physiological method	135
5.7.1	Aerodynamic recordings	135
5.7.2	Disadvantages with aerodynamic techniques	140
5.7.3	Data processing and analysis	141
5.7.4	Channel processing	142
5.7.5	Recordings	145
5.7.6	Labelling	147
5.7.7	Aerodynamic measurements	148
5.7.8	Ratio of maximum intra-oral pressure to peak oral flow in stops	148
5.7.9	The pressure impulse	149
5.7.10	Oral air-flow and intra-oral pressure	151
5.7.11	Timing measurements	152
5.8	The method for the analysis of geminates and voicing	153

5.8.1	Voice analysis	153
5.8.2	Glottal activity	154
5.8.3	Measurements	155
5.8.4	Spectral tilt and power spectra	159
5.9	The method for the analysis of nasals	161
5.9.1	Speakers	162
5.9.2	Acoustic duration measurements for nasals	165
5.9.3	Aerodynamic measurements for nasals	166
5.9.4	Aerodynamic timing measurements	168
6	An acoustic analysis of stops	171
6.1	Aims	172
6.2	Methods	172
6.3	Results: acoustic duration	173
6.4	Total medial stop duration	175
6.4.1	Place of articulation effects on stop duration within categories	177
6.4.2	Total consonant duration: separated by speaker	179
6.5	Stop structure: voice termination time, occlusion and voice onset time	186
6.5.1	Voice onset time	189
6.5.2	Voice onset time of initial stops	196
6.5.3	Voice termination time	198
6.6	Vowel duration	199
6.7	Results: burst analysis	202
6.7.1	Burst amplitude	203
6.7.2	A spectral analysis of the burst	204
6.8	Locus equations	207
6.9	Discussion	217
6.9.1	Duration	217
6.9.2	Voice onset time	218
6.9.3	Voice termination time	219
6.9.4	Vowel to consonant ratios	220
6.9.5	Non-durational measurements	220
6.9.6	Coarticulatory effects	221
6.9.7	Concluding remarks	222
7	An aerodynamic analysis of stops	223
7.1	Aims	224
7.2	Method	225
7.2.1	Speakers	225
7.2.2	Stimuli	225
7.2.3	Distribution	226
7.3	Results	228
7.3.1	Peak pressure vs. peak air-flow	229
7.3.2	Burst amplitude and intra-oral pressure at the release	232
7.3.3	Peak pressure vs. consonant duration	234

7.4	Results: the pressure impulse	236
7.5	Results: timing interactions–pressure and flow	238
7.5.1	Airflow timing and the following vowel	239
7.5.2	Oral air-flow in vowels preceding medial consonants	241
7.6	Discussion	244
7.6.1	Intra-oral pressure as independent of duration	247
7.6.2	Relative timing of air-flow peaks	249
7.6.3	Concluding remarks	251
8	Geminates, clusters and medial voicing	253
8.1	Method	254
8.1.1	Aims	254
8.1.2	Speakers	254
8.1.3	Stimuli	256
8.2	Geminates and long stops	256
8.2.1	Clusters	256
8.2.2	Geminates and clusters	258
8.3	Final stops	259
8.4	Aerodynamics	261
8.4.1	Geminates as clusters	261
8.5	Pressure impulse	263
8.5.1	Timing of Peak Pressure	265
8.6	Results: Medial Voicing Patterns	266
8.6.1	Spectral tilt and power spectra results	267
8.7	Discussion	271
9	Nasal coarticulation: an aerodynamic analysis	275
9.1	Aims	276
9.2	Results: an acoustic analysis of nasals	278
9.2.1	Duration results	278
9.2.2	Prestopped nasals	285
9.3	Results: aerodynamic analysis	286
9.3.1	Average flow rates	286
9.3.2	Nasalisation in VNV sequences	293
9.3.3	Normalised flow in NVN sequences	297
9.3.4	Average nasal airflow	297
9.3.5	Average nasal airflow in clusters	300
9.4	Results: timing in nasal sequences	307
9.4.1	Anticipation and delay of nasalisation	307
9.5	Results: nasal timing	310
9.5.1	Single nasals	310
9.6	Clusters	312
9.6.1	A cluster of nasal followed by a stop	316
9.6.2	A cluster of stop followed by a nasal	317
9.7	Discussion	320
10	Conclusion	323

10.1	Lenis and fortis	324
10.2	Coarticulation in nasals	329
10.3	Implications	330
10.4	Limitations of the study	332
10.5	Future work	333
References		337
Appendix A Abbreviations and Conversions:		377
A.1	Abbreviations	377
A.2	Abbreviations: phonological	378
A.3	Abbreviations: kinship	379
A.4	Abbreviations: glossing	380
A.5	Abbreviations: signals	381
A.6	Conversions: Aerodynamic	381
A.7	Conversions: Acoustic	381
A.8	Orthography	382
Appendix B Word Lists:		385
B.1	Corpus I	385
B.2	Corpus II	390

List of Figures

1	A map showing the location of Mamardawerre outstation and the approximate area in which Bininj Gun-wok and surrounding languages are spoken (Map by C.A. Stoakes after Harvey, 2002 and Evans, 2003)	xxiii
1.1	An approximate area in which dialects of Bininj Gun-wok (labelled in black) and surrounding languages (labelled in grey) are spoken (Map by C.A. Stoakes)	7
1.2	The vowel phonemes in Bininj Gun-wok	17
3.1	A schematic representation of the overlapping coarticulatory effects of three gestures, after Fowler and Saltzman (1993, p. 184)	65
4.1	Static palatogram showing the tongue shape for the velar tense stop [k:] in the word <i>bekka</i> , ‘file snake <i>Acrochordus arafurae</i> ’, from Butcher (forthcoming)	95

4.2	Static palatogram of a Kunwinjku utterance <i>bedda</i> ‘they’, showing tongue shape in the apico-alveolar stop, from Butcher (1995) redrawn from Jernudd (1974)	96
4.3	Static palatogram of a Kunwinjku utterance <i>wurdaw</i> ‘pax’, showing tongue shape in the apico-post-alveolar stop, from Butcher (1995) redrawn from Jernudd (1974)	97
5.1	Measurement criteria for medial voiced stops showing a medial bilabial lenis stop (realised as an approximant) [β] within the word <i>bobo</i> , ‘goodbye’	119
5.2	Measurement criteria for medial devoiced stops showing a medial bilabial fortis stop [p:] within the word <i>kabbal</i> , ‘floodplain’	120
5.3	An example of the hierarchy within the Emu Speech Database	124
5.4	Labelling of the onset (1), burst (2) and offset (3) within a medial fortis consonant [p:]	125
5.5	The locus equation plot for a hypothetical VC sequence	133
5.6	The measurement points for the locus equations within V ₁ and V ₂ surrounding an intervocalic consonant	134
5.7	The aerodynamic recording workstation at the field location	137
5.8	A record of the Kunwinjku word <i>kebbalhmeng</i> ‘to close your nose’ with in a carrier phrase, taken from PCQuirerX showing oral flow (U _o), oral pressure (P _o), nasal flow (marked here as N _o but elsewhere U _n) and Laryngograph traces (L _x).	138
5.9	A participant wearing the oral and nasal masks demonstrating the experimental configuration	140
5.10	An Aerodynamic record for a fortis stop	146
5.11	An Aerodynamic record for a lenis stop	147
5.12	A summary of measurements output from EGGWorks	157
5.13	The L _x signal and associated derived measurements	157
5.14	The derivative of an EGG signal	158
5.15	Measure of skew or speed quotient showing the closing and opening phases, figure reproduced from (Keating, Esposito, Garellek, Khan, & Kuang, 2012)	159
5.16	Spectral measurements on a spectral slice of a speech waveform.	160
5.17	Time normalised nasal measurement criteria	168
5.18	The measurement criteria for anticipation and delay	169
6.1	Stop durations separated by phonological stop category	176
6.2	The relative durations of lenis and fortis stops separated by voicing	177
6.3	Stop durations for fortis medial stops separated by phonetic label for Corpus I and Corpus II pooled	178
6.4	Mean consonant duration of medial stops separated by stop type (Corpus I)	183
6.5	Mean consonant duration of medial stops separated by stop type (Corpus II)	184
6.6	Different internal structures found in lenis and fortis stops separated by category as defined in Table 6.10	187

6.7	Positive Voice onset times pooled for the entire corpus	190
6.8	Positive Voice onset times separated by phonetic label for Corpus II	191
6.9	Negative Voice onset times separated by phonetic label for Corpus II	191
6.10	Voice onset times medial bilabial stops separated by speaker, Corpus II	192
6.11	Voice onset times medial velar stops separated by speaker, Corpus II	193
6.12	Voice onset times medial palatal stops separated by speaker, Corpus II	194
6.13	Voice onset times medial apico-alveolar stops separated by speaker, Corpus II	195
6.14	Summary of the voice onset times for initial stops stops, Corpus II	197
6.15	Voice onset times of initial stops by place of articulation, Corpus II	197
6.16	Voice termination time	198
6.17	The duration of vowels preceding fortis and lenis medial stops by speaker in Corpus.I	199
6.18	The duration of vowels preceding fortis and lenis medial stops by speaker in Corpus.II	200
6.19	The duration of vowels following fortis and lenis medial stops, Corpus I	200
6.20	The duration of vowels following fortis and lenis medial stops, Corpus II	201
6.21	The mean amplitude of V_2 compared with the mean burst amplitude (RMS amplitude measured in dB)	203
6.22	A spectral slice at three points within a medial bilabial consonant: at the burst, at the maximum RMS amplitude within the VOT and at 10 ms after the onset of the vowel for a male speaker (CM) for back vowels and front vowels	205
6.23	A spectral slice at three points within a medial bilabial consonant: at the burst, at the maximum RMS amplitude within the VOT and at 10 ms after the onset of the vowel for a female speaker (AB) for back vowels	206
6.24	A Spectral slice at three points within a medial velar consonant: at the burst, at the maximum RMS amplitude within the VOT and at 10 ms after the onset of the vowel for a female speaker (AB) for back vowels	207
6.25	Locus equation plot for bilabial stops in VC and CV sequences for male speakers	208
6.26	Locus equation plot for bilabial stops in VC and CV sequences for female speakers	209
6.27	Locus equation plot for velar stops in VC and CV sequences for male speakers	209
6.28	Locus equation plot for velar stops in VC and CV sequences for female speakers	210
6.29	Locus equation plot for alveolar stops in VC and CV sequences for male speakers	210

6.30	Locus equation plot for alveolar stops in VC and CV sequences for female speakers	211
6.31	Locus equation plot for palatal stops in VC and CV sequences for male speakers	211
6.32	Locus equation plot for palatal stops in VC and CV sequences for female speakers	212
6.33	Locus equation plot for retroflex stops in VC and CV sequences for male speakers	212
6.34	Locus equation plot for retroflex stops in VC and CV sequences for female speakers	213
7.1	Distribution of lenis and fortis in aerodynamic corpus stops by speaker	227
7.2	Intra-oral pressure (P_o shown on the <i>x-axis</i> in Pa) and Oral Flow (U_o shown on the <i>y-axis</i> in ml s^{-1}) for lenis and fortis stops separated by speaker	229
7.3	Intra-oral pressure (P_o in Pa) vs. Oral Flow (U_o in ml s^{-1}) for bilabial lenis and fortis stops separated by word	230
7.4	Peak Intra-oral pressure (P_o Pa) against RMS Amplitude (dB) separated by stop category and by speaker	232
7.5	Peak Intra-oral pressure (P_o Pa) against RMS Amplitude (dB) separated by stop category and by speaker	233
7.6	Peak oral flow (U_o cm^3/s) against RMS Amplitude (dB) separated by stop category and by speaker	234
7.7	The time to reach peak intra-oral pressure by stop category . . .	235
7.8	The time to reach peak intra-oral pressure by stop category and speaker	235
7.9	The area under the intra-oral pressure (P_o) curve (shaded) for an intervocalic fortis stop - The Pressure Impulse	236
7.10	The differentiated area under the intra-oral pressure curve (Pressure Impulse) separated by lenis and fortis stops (shown in pascal.seconds (Pa.s))	237
7.11	The differentiated intra-oral pressure curve (Pressure Impulse) separated by lenis and fortis stops and speaker (in pascal.seconds (Pa.s))	238
7.12	The peak oral air flow (U_o^{MAX})—marked with the vertical line in red— for a fortis stop in the word <i>kabbal</i> – speaker RN	239
7.13	The peak oral air flow (U_o^{MAX})—marked with the vertical line in red— for a lenis stop in the word <i>kabo</i> – speaker DD	240
7.14	Timing of Oral flow peak with respect to the vowel onset (ΔU_o^{MAX})	241
7.15	Oral Airflow (U_o) and Glottal Activity (L_x) for a bilabial fortis stop <i>kabbal</i> ‘flood plain’ for speaker CM	242
7.16	Oral airflow (U_o) and glottal activity (L_x) for a bilabial fortis stop <i>kabbal</i> ‘flood plain’ for speaker EN	243
7.17	Oral airflow (U_o) and glottal activity (L_x) for a bilabial lenis stop <i>bobo</i> ‘goodbye’ for speaker RN	243

7.18	Oral airflow (U_o) and glottal activity (L_x) for a bilabial lenis stop <i>kabo</i> ‘green ant’ for speaker CM	244
7.19	Oral airflow (U_o) and glottal activity (L_x) for a bilabial lenis stop <i>bobo</i> ‘goodbye’ for speaker DD	245
7.20	Oral airflow (U_o) and glottal activity (L_x) for a palatal lenis stop <i>yidjare</i> ‘you want’ for speaker CM	245
7.21	A medial apical fortis stop in the word <i>kaddum</i> ‘above’ for speaker DD	250
8.1	Medial cluster durations by speaker, Corpus I	257
8.2	Lenis, Geminate and Fortis stops, Corpus II	258
8.3	Lenis, Geminate and Fortis stops, Corpus II	259
8.4	Duration of final stops, Corpus II	260
8.5	A medial fortis stop in the word ‘kabbal’ spoken by CM	261
8.6	A medial geminate cluster in the word ‘kebbalhmeng’ spoken by CM	262
8.7	A medial geminate cluster in the word ‘kebbereh’ spoken by CM	262
8.8	Pressure impulse showing lenis and fortis stops and geminate clusters	263
8.9	Pressure impulse showing lenis and fortis stops and geminates separated by speaker	264
8.10	Timing of Oral flow peak with respect to the vowel onset (ΔU_o^{MAX}) separated by lenis, fortis and geminate	266
8.11	Male speakers (HK, OK, DK) showing H1*-H2* measurements across time in VC:V (fortis), VCCV (geminate) and VCV (lenis) sequences measured from the acoustic signal	269
8.12	Female speakers (MM, JM) showing H1*-H2* measurements across time in VC:V (fortis), VCCV (geminate) and VCV (lenis) sequences measured from the acoustic signal	270
9.1	Summary of duration measurements in single nasals (N) and nasal clusters (CN) and (NC)	284
9.2	Average airflow of bilabial nasals in a time normalised sequence of V followed by N in a VNV sequence	294
9.3	Average airflow of apical nasal in a time normalised sequence of a VNV sequence	295
9.4	Average airflow of palatal nasal in a time normalised sequence of a VNV sequence	296
9.5	Average airflow of retroflex nasal in a time normalised sequence of a VNV sequence	296
9.6	Average airflow of velar nasals in a time normalised sequence of a VNV sequence	297
9.7	Average airflow of time normalised N ₁ VN ₂ sequences for all speakers	298
9.8	Average airflow of bilabial nasals in a time normalised sequence of V followed by N in a VNV sequence separated by vowel	299

9.9	Average airflow of velar nasals in a time normalised sequence of a VNV sequence separated by vowel	299
9.10	Average airflow of apico-alveolar nasal in a time normalised sequence of a VNV sequence separated by vowel	300
9.11	Airflow of bilabial nasals in a time normalised sequence VCNV for all speakers	304
9.12	Airflow of velar nasals in a time normalised sequence VCNV for all speakers	305
9.13	Airflow of apico-alveolar nasals in a time normalised sequence VCNV for all speakers	305
9.14	Average airflow in a time normalised VNCV sequence for bilabial nasals averaged across all speakers	306
9.15	Airflow in a time normalised VNCV sequence for apico-alveolar nasals averaged across for all speakers	306
9.16	The duration of anticipation (a), delay (d) and carry-over (c) relative to the onset or offset of a nasal	308
9.17	The duration of anticipation (a), delay (d) and carry-over (c) relative to the onset or offset of a nasal separated by speaker	309
9.18	The ratio of anticipation (a), delay (d) to the segment preceding a nasal and carry-over (c) relative to the segment following a nasal separated by speaker	310
9.19	Nasal (U_n) air flow and acoustic waveform for a VNV sequence in the word <i>kamak</i> ‘good’	311
9.20	Nasal (U_n) air flow and acoustic waveform for a VNV sequence in the word <i>bininj</i> ‘man’	312
9.21	The time from the oral closure until the maximum rate of change in the nasal flow rate ($f'(U_n)$) (ms) separated by speaker	313
9.22	Nasal (U_n) air flow and acoustic waveform for an heterorganic nasal plus stop cluster (VNCV)	314
9.23	The time from the oral closure until the maximum flow rate (U_n^{MAX}) (ms) separated by speaker	314
9.24	Nasal (U_n) air flow and acoustic waveform for an homorganic stop plus nasal cluster (VCNV)	315
9.25	Nasal (U_n) air flow and acoustic waveform for an heterorganic stop plus nasal cluster	315
9.26	Oral (U_o) and nasal (U_n) air flow, intra-oral pressure (P_o) and acoustic waveform for an heterorganic stop plus nasal cluster (VNCV) in the word <i>manbandarr</i> speaker BN	316
9.27	Oral (U_o) and nasal (U_n) air flow, intra-oral pressure (P_o) and acoustic waveform for an heterorganic stop plus nasal cluster (VnbV) in the word <i>lonbom</i> , speaker BN	317
9.28	Oral (U_o) and nasal (U_n) air flow, intra-oral pressure (P_o) and acoustic waveform for an heterorganic stop plus nasal cluster (VpɲV) in the word <i>kebngakmeng</i> , speaker BN	318
9.29	Oral (U_o) and nasal (U_n) air flow, intra-oral pressure (P_o) and acoustic waveform for an homorganic stop plus nasal cluster (VpmV) in the word <i>bebmeng</i> , speaker BN	319

9.30	Oral (U_o) and nasal (U_n) air flow, intra-oral pressure (P_o) and acoustic waveform for an heterorganic stop plus nasal cluster ($Vp\eta V$) in the word <i>kebngakmeng</i> , speaker DJ	320
------	---	-----

List of Tables

1.1	The consonant inventory of Bininj Gun-wok	14
1.2	Diphthongs in Bininj Gun-wok with relative prominence from Evans (2003)	18
2.1	The differences between “tense and lax” in Korean	37
2.2	Acoustical features of “tense and lax” stops in Korean	38
2.3	Articulatory features “tense and lax” stops in Korean	38
4.1	Average durations (in ms) of fortis and lenis stops in six Gunwinnguan languages related to Bininj Gun-wok (summarised in Butcher (2006b)	79
4.2	Average durations (in ms) of fortis and lenis stops in three languages (from Harvey p.c. reported in Butcher, 2006b)	79
4.3	Average durations of geminates (fortis) and singletons (lenis) in Ngalakgan (measured in ms) with number of tokens in parentheses (Baker, 2008)	80
4.4	Jarwon lenis (short) and fortis (long) stop durations (in ms) separated by place of articulation (from Jaeger 1983 p.183)	81
4.5	Australian languages with fricatives	85
5.1	The distribution of tokens in Corpus I by speaker	109
5.2	The distribution of tokens in Corpus II by speaker	109
5.3	Distribution of speakers by sex	110
5.4	Word lists: A—fortis stops, B—lenis stops and C—geminate stops	113
5.5	Formats for Aerodynamic Recordings	143
5.6	Formats for Aerodynamic Recordings	143
5.7	Acoustic and Aerodynamic filtering methods	144
5.8	Voice analysis measurements output from Voicesauce Shue, Keating, Vicenik, and Yu (2011); Shue, Keating, and Vicenik (2009)	160
5.9	Nasal word list (N)	163
6.1	Mean ($\bar{x}$), standard deviation (σ) and minima and maxima for lenis and fortis medial stop durations, measured in milliseconds (ms)	173

6.2	Summary of statistical analysis for lenis and fortis medial stop durations for tokens in position 1 (focussed) in ms	174
6.3	Summary of statistical analysis for lenis and fortis medial stop durations for tokens in position 2 (unfocussed) in ms	174
6.4	Number (n), mean duration ($\bar{x}$), median duration ($\tilde{x}$) and standard deviation (σ) of fortis and lenis stop durations, separated by speaker for the both corpora (I and II)—all measurements in milliseconds (ms)	180
6.5	Summary for speaker DN, number (n), mean duration ($\bar{x}$), median duration ($\tilde{x}$) and standard deviation (σ) of fortis and lenis stops, all measurements in milliseconds (ms) (Corpus I)	181
6.6	Summary for speaker HK, number (n), mean duration ($\bar{x}$), median duration ($\tilde{x}$) and standard deviation (σ) of fortis and lenis stops, all measurements in milliseconds (ms) (Corpus I)	181
6.7	Summary for speaker OK, number (n), mean duration ($\bar{x}$), median duration ($\tilde{x}$) and standard deviation (σ) of fortis and lenis stops, all measurements in milliseconds (ms) (Corpus I)	182
6.8	Summary for speaker JM, number (n), mean duration ($\bar{x}$), median duration ($\tilde{x}$) and standard deviation (σ) of fortis and lenis stops, all measurements in milliseconds (ms) (Corpus I)	182
6.9	Summary for speaker MM, number (n), mean duration ($\bar{x}$), median duration ($\tilde{x}$) and standard deviation (σ) of fortis and lenis stops, all measurements in milliseconds (ms) (Corpus I)	182
6.10	Summary of Stop types in Bininj Gun-wok combining VTT, cessation of voicing and VOT	186
6.11	Distribution of stop category by stop composition (type)	188
6.12	Presence and absence of clear release bursts in lenis and fortis stops found in Corpus II (Frequency)	189
6.13	Summary of mean VOTs (ms) in lenis and fortis medial stops for ten speakers in Corpus II	190
6.14	Locus Equation Summary for stops (fortis and lenis) in VC sequences, Males	214
6.15	Locus Equation Summary for stops (fortis and lenis) in CV sequences, Males	214
6.16	Locus Equation Summary for stops (fortis and lenis) in VC sequences, Females	215
6.17	Locus Equation Summary for stops in CV sequences, female speakers	215
7.1	Word list - Aerodynamic	226
7.2	Distribution of words by speaker within in the corpus	227
7.3	Number (n), mean maximum oral flow rate ($\bar{U}_o$) measured in cubic centimetres per second ($\text{cm}^3 \text{s}^{-1}$), mean maximum oral pressure ($\bar{P}_o$) measured in Pascals (Pa) for bilabial fortis and lenis stops separated by speaker	228
8.1	Word list - Aerodynamic: Geminates	256

9.1	Duration of singleton nasals (VNV) (ms)	279
9.2	Duration (ms) of medial singleton nasals in words within a carrier phrase (a)	280
9.3	Duration (ms) of medial singleton nasals in words within a carrier phrase (b)	280
9.4	Duration of nasal (N_1) + stop (C_1) clusters and the individual segments in CVNCV sequences (ms), mean ($\bar{x}$), standard deviation (<i>s.d.</i>) and number (<i>n</i>)	281
9.5	Duration of stop (C_1) + nasal (N_1) clusters and segments (mean, standard deviation and number) in CVCNV sequences (ms)	282
9.6	The duration of prestopped nasals (ms)	285
9.7	Mean nasal airflow ($\bar{U}_n$) of segments in VNV sequences (measured in $\text{cm}^3 \text{s}^{-1}$)	288
9.8	Mean oral airflow ($\bar{U}_o$) of segments in VNV sequences (measured in $\text{cm}^3 \text{s}^{-1}$)	288
9.9	Mean nasal airflow ($\bar{U}_n$) of segments in VNV sequences (measured in $\text{cm}^3 \text{s}^{-1}$) separated by speaker	289
9.10	Mean oral airflow ($\bar{U}_o$) of segments in VNV sequences (measured in $\text{cm}^3 \text{s}^{-1}$) separated by speaker	290
9.11	Percentage of Nasal Flow as a proportion of total flow ($U_o + U_n$) of segments in VNV sequences (%)	291
9.12	Average Nasal airflow in NC clusters	302
9.13	Average Oral airflow in NC clusters	302
9.14	Average Nasal airflow in CN clusters	303
9.15	Oral airflow in CN clusters	303
9.16	Percentage of tokens with anticipated and delayed nasalisation .	307
10.1	Acoustical features of lenis and fortis stops in Bininj Gun-wok . .	326
10.2	The differences between fortis, lenis stop categories and geminates in Bininj Gun-wok	327
A.1	Orthographic system for Kunwinjku (Bininj Gun-wok) (from Evans, 2003)	382
A.2	Orthographic system for Gundjeihmi (Bininj Gun-wok) (from Evans, 2003)	383
A.3	Orthographic system for Manyallaluk Mayali (Bininj Gun-wok) (from Evans, 2003)	383

Location Map

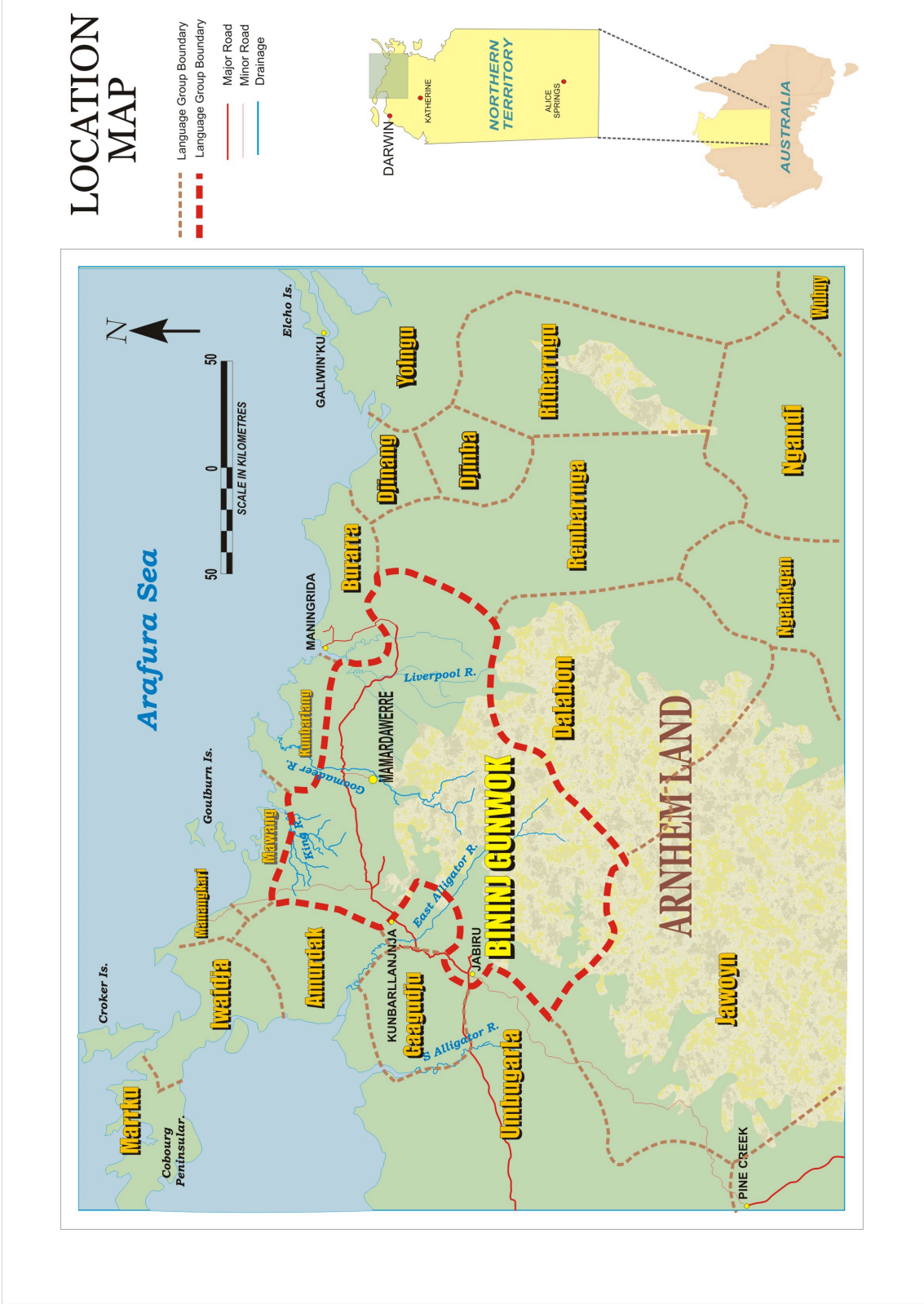


FIGURE 1: A map showing the location of Mamardawerre outstation and the approximate area in which Bininj Gun-wok and surrounding languages are spoken (Map by C.A. Stoakes after Harvey, 2002 and Evans, 2003).

Chapter 1

Introduction

This dissertation is an instrumental phonetic analysis of the consonant system in Bininj Gun-wok. The primary aim of this work is to provide a detailed phonetic description of an Australian language with a particular focus on intervocalic stops and nasals. By examining intervocalic stops there is the possibility to make use of transitional acoustic information found at both the onset and offset of stop consonants and to correlate this with aerodynamic data. This in turn enables the examination of coarticulatory effects, including the assimilation of place of articulation, voicing and nasalisation. The experiments below detail the results of the first multi-channelled instrumental phonetic study involving multiple male and female speakers of an Australian language. It investigates general theories of acoustic and articulatory phonetics and phonology in relation to Australian languages. Through the use of acoustics, aerodynamics and electroglottography, the acoustic and articulatory phonetic properties of consonants in Bininj Gun-wok are thoroughly examined.

Most languages of the world exhibit a phonological contrast between stop series, however this is not typically found in many languages of Australia. The Australian languages are commonly described phonologically as displaying a single series of stops that does not contrast for voicing. This is an oversimplification, which is highlighted by a small subset of languages—including Bininj Gun-wok—in which a stop contrast is found at all places of articulation. The

phonetic differences between these contrastive medial stops have not been subjected to systematic description, although there is a well documented difference in phonemic length. Phonetic differences between the stops categories could give a valuable insight into the patterns of contrastive voicing in stops within the language and across Australian languages generally.

A major motivation for this study is to describe the underlying phonetic mechanisms used in the articulation of medial consonants in Bininj Gun-wok. A hypothesis that is central to this thesis is Butcher's place of articulation imperative for Australian languages (Butcher, 2006a, forthcoming), which says that maximising the perceptual cues for intervocalic consonants is of prime importance in languages with many places of articulation. Butcher shows that the majority of perceptually important phonetic contrasts in Australian languages are found in the transitions between consonants and vowels based on extensive examination across Australian languages (Butcher, 2006a).

This thesis will also investigate the production of medial nasals and the directionality of nasal coarticulation in Bininj Gun-wok. Patterns of nasalisation may show that the spread of nasalisation from a nasal segment is limited. It is thought from cross-linguistic research that anticipatory nasalisation is under the direct control of the speaker whereas carry-over nasalisation is related to the physiology nasal articulations (Ohala, 1975; Ohala & Ohala, 1993). Both medial stops and nasals will be investigated with a variety of phonetic analysis methods in order to investigate this important prosodic position in the language.

Bininj Gun-wok [ˈpɪnɪŋ ˈkunwək̚] is a Non-Pama-Nyungan language spoken in Western Arnhem Land, an area of the Northern Territory of Australia. The dialect, Kunwinjku Kunwok [ˌkunˈwiŋgu ˈkunwək̚] is spoken by the people who live on the Northern side of the Arnhem plateau (refer to the maps shown on pages xxiii and 7). Kunwinjku refer to themselves reflexively as Bininj, and this term can be extended to reference all Australian Aboriginal People belonging

to the subsection system.¹ The term *Kunwok* (Gun-wok) is the nominal term for ‘speech’ or ‘words’ which represents ‘language’. For example, Bininj use the term *Balanda Kunwok* to refer to ‘Standard Australian English.’² This thesis uses spoken language from the Kunwinjku dialect of Bininj Gun-wok with additional data from other dialects where available.

Initially, I will outline the segmental phonology of Bininj Gun-wok and then briefly describe the syllabic structure in sections § 1.3 and § 1.3.2 which focus on the parts of the phonology that are directly relevant to the experimental design of the current study. The majority of the phonological, phonotactic and morphological background has been drawn from *Bininj Gun-wok: a Pan-dialectal Grammar* which is a comprehensive grammar of Bininj Gun-wok encompassing all of the dialects (Evans, 2003), and aspects of social organisation and pragmatic language usage from *Social Deixis in Bininj Kun-wok Conversation* (Garde, 2002).³⁴

¹This kinship system is central to Bininj culture and all members of society belong to a particular subsection. More information can be found in Garde (2002, p. 37).

²*Balanda* comes from the Makassarese word *balanda*, borrowed from the Malay *belanda* which in turn derives from *Hollander* originally taken to mean ‘Dutchman’. It is usually restricted in reference to non-Aboriginal people.

³Evans (2003) is reviewed in Baker (2004)

⁴Note that Garde uses an alternate spelling of Bininj Gun-wok which reflects the orthographic conventions of the Kunwinjku, Kuninjku and Kune dialects. These dialects employ the grapheme <ƙ> for all velar oral stops whereas others such as Gundjeihmi, use a <g> grapheme in syllable initial position and a <ƙ> grapheme in final position (see A.8 in Appendix A.8 for an explanation of orthographic conventions in the various dialects). I use the spelling for the Bininj Gun-wok word *Gun-wok* that employs the grapheme <g> and a hyphen between the nominal prefix and the word root for the sake of consistency with other linguistic writing on the language, particularly that by Evans (2003)

1.1 Bininj Gun-wok: people and language

The language Bininj Gun-wok—which has also referred to previously linguistic and anthropological literature as Gunwinggu, Gunwinygu, Mayali or Neninggu (Dixon, 2002)—is a dialect chain spoken across Western Arnhem Land which consists of the varieties, Kunwinjku, Kuninjku, Gundjeihmi, Kundedjnjenghmi, Kune and Manyallaluk Mayali.⁵ These are shown on the map (Figure 1.1) with dialects of Bininj Gun-wok shown in bold and the adjacent languages shown without emphasis. The shaded area shows the approximate region in which the language is currently spoken.⁶ There are approximately 2000 speakers of all dialects combined, whereas the 2011 Australian Census recorded the number of speakers as 1639 (The Australian Bureau of Statistics, 2011). The Gundedjnjenghmi and Kuninjku dialects are severely endangered (Evans, 2003).

Bininj Gun-wok is one of only a few Australian languages currently passed on to children.⁷ The Kunwinjku and Gundjeihmi dialects of Bininj Gun-wok, in particular, have subsumed many of the surrounding dialects and language groups as a first language. Kunwinjku was used as the mission language at Kunbarlaninja and became the lingua franca for the cattle industry in the area. Gundjeihmi is the variety spoken at the settlement of Jabiru in Kakadu National Park (Evans, 1989).

Bininj Gun-wok is classified as a member of the Gunwinyguan subgroup

⁵Manyallaluk Mayali is a more recent ‘koiné’ formed early last century when various Bininj Gun-wok speakers moved south to the mining community of Eva Valley (Manyallaluk). The dialect is grammatically quite distinct from the other Bininj Gun-wok varieties (Evans, 2003, p. xxii).

⁶This map and the language map at the front of this thesis are based on research by Harvey (2002, p. xiv-xv) and also adapted from maps in Evans (2003, p. xxix) and Evans (2010, p. 7).

⁷It should be noted that only some of the dialects (Kunwinjku, Kuninjku and Kune) have active child language acquisition at the expense of other dialects and neighbouring languages (Bishop, 2002b, p. 2).

originally proposed by O'Grady, Voegelin and Voegelin (1966). The Gunwinyguan (Kunwinjku) group is the largest of the Non-Pama-Nyungan language families, consisting of the languages: Jawoyn (also known as Djauan or Jarwoñ), Ngandi, Nunggubuyu (Wubuy), Kungarakany, Kunbarlang, Mangarayi, Alawa, Marra, Wandarang, Ngalkbun (Dalabon), Ngalakan (Ngalakgan), Rembarrnga, Wagiman (Wageman), Waray, Dagoman, Wardaman and Yangman.⁸ In addition languages such as Burarra, Anindilyakwa (Enindhilyagwa) and Gaagadu (Gaagadju) have also previously been considered as having linguistic relatedness, but there is some debate regarding their inclusion within the Gunwinyguan language family (see Harvey, 2002, p.15 and Wurm, 1972).

In this study, data from a selection of the major dialects or varieties of Bininj Gun-wok are considered; with the majority of these data being collected from Kunwinjku and Kuninjku speakers. The Kunwinjku people are made up of a group of clans with estates roughly centred around the settlement of Mamardawerre near to the Goomadeer [gomeɖ:ɛr] River.⁹ Kunwinjku, the name of the people and the language, is based on the nominal root *-winjku* meaning 'freshwater'. Freshwater people are contrasted with the coastal people directly to the North (predominantly speakers of Mawng, Kunbarlang and/or Iwaidja) who are characterised as having a 'saltwater' socio-cultural affiliation (Evans, 2003, p. 11). The partitioning of people and society based on geographical

⁸Spelling of language names are per the entry in *Ethnologue* (Lewis, 2009) and does not include alternative names and spellings and in addition does not use the modern orthographic conventions. Some of these languages are more accurately termed dialects of the same language and many have only a distant typological relatedness to neighbouring languages. I will use these labels where possible to refer to the languages related to Kunwinjku and Bininj Gun-wok in general, so they can be compared with the previous literature. Additionally, I will note when an alternate spelling is employed. At the time of writing many of these languages have no active speakers or are down to a handful of first language speakers.

⁹Mamardawerre is an outstation of Gunbalanya (*Kunbarllaninja* in local orthography and formerly named Oenpelli) which was resettled in the late 1950s as a direct result of the homeland movement (see Wilson (2005) for a brief history).

proximity to water is common throughout Northern Australia. In addition to this geographical relationship to identity, there are many other relationships with local ecology too numerous to list here (Telfer & Garde, 2006).

Bininj Gun-wok is a language group consisting of related—and mutually intelligible—varieties or dialects. Despite their mutual intelligibility there are significant dialectal differences found within the group and between the varieties. These differences are discussed in detail by Evans (2003). This study will not investigate these differences, and this is mainly because the dialects are considered phonemically homogeneous by Evans (2003). There is however some variation in phonetic vowel realisation and at the lexical and morpho-phonemic level. the differences in vowel quality, are mainly restricted to the diphthongs. In addition there is extensive deletion of initial segments, commonly nasals—most notably in the Gundjeihmi and Kuninjku varieties. This study is not a comparison of the dialects of Bininj Gun-wok but rather a study of the language as a whole. Where possible, data are drawn from multiple dialects, with the focus on the Kunwinjku and Kuninjku dialects where more data are available.

As discussed by Evans (2003, p. 8), the dialects and their associated names are a division of convenience. The exact boundaries for speakers is more clearly delineated by clan membership. For this reason it is possible to further subdivide the dialects of Bininj Gun-wok to the level of clan-lects and each clan-lect may have elements in common with two or more of these dialects from a lexical or structural perspective. Language is intrinsically tied to a geographical area for Bininj Gun-wok speakers.¹⁰ It is of great importance to the people involved in this study that only words drawn from the dialect spoken in the location where experiments were recorded were included. Consequently, in this study, word lists are tailored to a particular dialect and even down to the

¹⁰This is broadly true of speakers of First Australians in general. As noted above, ecology is intertwined with many aspects of language and identity (Garde, 2002; Mark & Turk, 2003).

level of the particular clan-lect of the people living in the area.¹¹ Where known and recorded, I will include the dialect name, gloss and English meaning of the referred lexeme.¹²

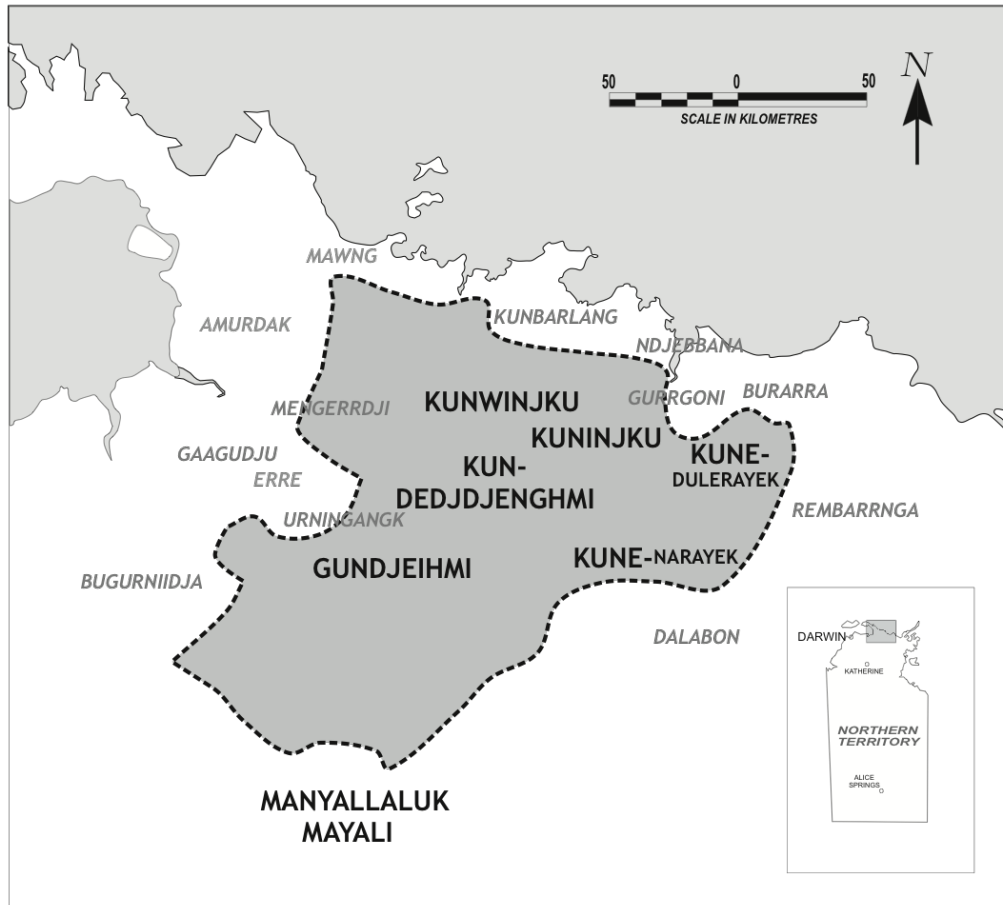


FIGURE 1.1: An approximate area in which dialects of Bininj Gun-wok (labelled in black) and surrounding languages (labelled in grey) are spoken (Map by C.A. Stoakes).

¹¹For more information about clan-lects and for a discussion on the dialects and sub-dialects (clan-lects) of Bininj Gun-wok see Garde (2008a). Garde argues that that the sub-dialects of Bininj Gun-wok are *Ausbau* in contrast to *Abstand* languages (Kloss, 1967).

¹²The majority of the recordings used in this thesis are from speakers of Kunwinjku. When the recordings come from other Bininj Gun-wok dialects it will be noted in the text.

1.2 Previous linguistic research on Bininj Gun-wok

Traditionally, Australian languages are categorised in two distinct language groups based upon linguistic relatedness. The Pama-Nyungan languages spoken in the Southern and Eastern parts of Australia—with a pocket in Eastern Arnhem land—are a typologically related group of languages which were, until the modern era spoken throughout the majority of the Australian continent. The Non-Pama-Nyungan languages, spoken in the Northern Territory and the Northern part of Western Australia, are a distinct group of languages with a linguistic relatedness that is complex and unclear. Although there are many structural differences, both syntactic and lexical, within and between the Pama-Nyungan and the Non-Pama-Nyungan language families, the phonologies, and to a lesser extent the phonetics, have surprising similarity. The majority of Pama-Nyungan languages are dependent marking languages (Nichols, 1986) that use suffixes with no prefixing, whereas the Non-Pama-Nyungan languages are highly morphologically complex and use both prefixing and suffixing (Dixon, 2002). Bininj Gun-wok is classified as a Non-Pama-Nyungan language which can have up to 12 prefixes and three suffixes on verbs and three prefixes with maximally five suffixes on nouns (Evans, 2003, 2004).

This description and experimental analysis of the phonetics of Bininj Gun-wok is informed by the research of many previous studies both linguistic and anthropological. Any investigation into language draws on the research of other disciplines; as a source for elicitation of possible word paradigms as well as a basis for simple word lists. Anthropological research into kinship and social organisation is particularly important when conducting fieldwork in Australian remote communities, as is the research of the local ecology. Space does not allow me to detail the socio-cultural complexities of Kunwinjkuan life, however.

For a comprehensive survey of the literature regarding Bininj and Bininj Gun-Wok, see Garde (2002, p. 26–29). Additionally, Garde (2002) provides a

detailed description of the kinship and socio-linguistic aspects of Biniŋ Gun-wok. Seminal linguistic and ethnographic writing on Biniŋ society and culture was gathered by Arthur Capell (1942), Ronald and Catherine Berndt (Berndt, 1951; Berndt & Berndt, 1951; Berndt, 1951; Berndt & Berndt, 1970). The Berndt studies are ethnographical in focus, but include significant amounts of transcribed linguistic material much of it from Kunwinjku and particularly the variety that is recorded in this study which provides a rich source of lexical information.

There are also detailed but largely unpublished language notes on Kunwinjku and related languages recorded by the prodigious linguist Ken Hale (cited in Evans (2003)). A number of sketch grammars, dictionaries and teaching manuals have also been written and these provide a significant basis for further language maintenance and linguistic research (Carroll, 1976; Etherington, 2006; Etherington & Etherington, 1998; Garde, 2011; Harris, 1969; Oates, 1964).

An aspect of Biniŋ Gun-wok grammar that has been extensively covered in the linguistic literature is noun incorporation (Mithun, 1984). This is expanded on by Evans (1997) and noun incorporation is directly relevant to the current study as this feature of the language provides the environment for an unusual variety of possible medial clusters at all places of articulation. Despite the extensive ‘pan-dialectal’ grammar of Biniŋ Gun-wok completed by Evans (2003), further research is required in order to complete the grammars of the individual varieties.

The interface between linguistic organisation and social organisation is central to Garde’s (2002) research on tri-relational kinship terms and clan affiliation. Garde is in the process of compiling a comprehensive dictionary of Biniŋ Gun-wok, mainly focussed on the *Kuninjku* and *Kundedjengehmi* dialects (Garde, forthcoming). A subset of this is compiled in a dictionary of Biniŋ Gun-wok medical terms designed for clinical applications (Garde, 2011). The combination of in-depth consultation with Kunwinjku speakers and textual sources

make up all of the linguistic material included as part of this study.

Experimental research from a phonetic perspective by Jernudd (1974) describes Kunwinjku stop articulation. This study remains unusual due to the addition of some static palatography in the results. Carroll (1976) uses these results as the basis of his phonetic descriptions of Kunwinjku stops. The phonetic investigations of Jernudd (1974) and Carroll (1976) and the research on phonetics of Australian languages in general are discussed in greater detail the sections below (§ 1.4 and § 4.4).

The segmental phonetics of a language is situation within a higher order prosodic structure. Knowledge of the prosodic structure of a language is vital to any description of articulatory movements. A major analysis of the phonological stress and prosodic system in Bininj Gun-wok was undertaken by Bishop and this is reported in Bishop (2002b) and Bishop and Fletcher (2005).

1.3 The phonology of Bininj Gun-wok in an Australian context

There are notable similarities between the phonemic inventories of Australian languages. They are classified as a single genetic phylum that has both geographical and linguistic separation due to a significant time depth (Dixon, 2002; Evans & Merlan, 2004). There are a large number of place-of-articulation distinctions but a reduced number of manner-of-articulation distinctions and relatively restricted vowel spaces (Butcher, 1994, 2006a). Australian languages typically have, what have been described as, ‘long flat’ phonologies (Butcher, 1996), with numerous ‘place of articulation’ distinctions but fewer ‘manner of articulation’ distinctions (Butcher, 2006a). Australian languages generally have nasal phonemes matched at every place of articulation to an oral stop phoneme (Dixon, 2002; Hamilton, 1996). Furthermore, they have laterals that match oral stops at the places of articulation incorporating the coronal articu-

lateral (Hamilton, 1996; Tabain & Butcher, 1999a, 1999b). Coronals are phones that involve the tip (or crown) or the tongue in the articulation (Butcher, 1995). This thesis will follow the definitions used by Hamilton (1996, p. 36) for stops, nasals and laterals in Australian languages. In his phonological analysis he uses the term ‘stop’ to cover obstruent oral stops, ‘nasal’ for the class of sonorant nasals and ‘lateral’ for the class of lateral sonorants. Generally the subclass of consonants, termed obstruents, include plosives and fricatives but as the majority of Australian languages, including Biniŋ Gun-wok, lack phonemically contrastive fricatives, this means that oral obstruents are phonologically restricted to stops. For the remainder of this study the term ‘stop’ is used when referring to an ‘oral plosive’ and ‘nasal’ to include ‘nasal stops’ following Hamilton’s (1996) convention.

Most Australian languages are described as having only a single oral stop series with no phonological distinction between voiced and voiceless stops. There are some restrictions on the position within a word that a voiced allophone can appear however and there is phonetic consistency speaker to speaker. As Wurm (1972, p. 45, cited in Austin 1988) contends,

The distinction between ‘voiced’ and ‘voiceless’ stops is of relevance only for the few languages which have two contrastive orally released stop series. In most of these languages, the contrast between the two series is based more on a tense-lax distinction than a voiceless-voiced distinction.

Biniŋ Gun-wok has two stop series that contrast but not in terms of voicing. The underlying phonetics of the distinction is not well understood however, meaning that a tense-lax categorisation cannot be applied without further scrutiny. What is well known is that there is phonological difference between the stop series and that the obvious phonetic correlate of this is duration. This length difference has previously provided grounds to label them as ‘short’ and

‘long’ (Evans, 2003). This study uses the terms ‘lenis’ and ‘fortis’ in preference to terms such as tense and lax, long or short or voiced or voiceless for labels to differentiate the two stop series in Bininj Gun-wok.¹³

Bininj Gun-wok has a phoneme inventory of twenty-two consonants and five vowels (see § 1.1 and § 1.2). The consonant inventory has paired oral stops and nasals at all places of articulation except the glottal stop. The consonant phoneme inventory is grouped into two main categories, peripherals and coronals. The peripheral category groups the bilabial and velar places of articulation together despite not sharing a place of articulation (Dixon, 1980, 2002; O’Grady et al., 1966). This grouping is used in order to greatly simplify explanations of phonotactics within Australian languages (Hamilton, 1996). The coronal class includes phonemes that are articulated with the tip or blade of the tongue raised toward the hard palate. The coronal sounds can be further divided into apical and laminal articulations. It is usual in linguistic studies of Australian languages for the dentals and palatals to be grouped together into the class ‘laminal’, which both use the blade of the tongue as the active articulator. Alveolar and post-alveolar (retroflex) sounds are grouped together as ‘apicals’ as they share the tip of the tongue as the active articulator (Butcher & Tabain, 2004; Jernudd, 1974).

Bininj Gun-wok has six peripheral phonemes: bilabial and velar, short (lenis) and long (fortis) stops (/p, p:, k, k:/) and a bilabial nasal /m/ and velar nasal /ŋ/. Within the coronal class, the apicals have the widest array of manner of articulation contrasts. Apicals are both long (lenis) and short (fortis) stops (/t, t:, ɬ, ɬ:/), nasals (/n, ŋ/), lateral approximants (/l, ɭ/), approximants (/ɻ, ɻ:/) and a trill (/r/). Butcher (forthcoming, p. 3) labels palatals—denoted in the IPA as [c]—with the phonetically more accurate term ‘alveo-palatals’ and employs the IPA symbol [ç] with the addition of the ‘advanced’ diacritic to indicate that the place of articulation is more anterior. This study uses the voiceless palatal

¹³Note that I will not be using the plural forms lenes and fortes.

plosive symbol /c/ to refer to stop phonemes at the alveo-palatal place of articulation. These can be either fortis or lenis and denoted with the following symbols [c:] [c] or [ɟ] rather than the alternative alveo-palatal stop symbol [tʃ] (see § 4.4 for further detail on the phonetic contrasts).

Although Biniŋ Gun-wok has a double apical series with both apico-alveolar and apico-postalveolar places of articulation, the language does not have the double laminal series found in many Australian languages. The double apical series is in the phonologies of geographically adjacent languages, for example Yolŋu Matha, which has both lamino-palatal and lamino-dental stops and nasals found in its phonology (Wilkinson, 1991, p. 41).

As shown in Table 1.1, Biniŋ Gun-wok's two rhotic phonemes are grouped together despite the apico-alveolar segment often articulated as a trill or a single tap whereas the segment marked as apico-retroflex by Evans (2003, p. 78), often articulated as a continuant. This arrangement shows their phonological relatedness but does not infer any alternate phonetic relationship. It is unclear from phonetic data gathered as part of the current study whether the /ɻ/ phoneme is realised as an alveolar approximant [ɻ] or as a retroflex [ɻ̠] as suggested by Evans (2003, Table 2.3 on p. 78). My own observations suggests that it is not a retroflex phone but could be realised phonetically as a post-alveolar approximant lacking sub-laminal—involving the lower surface of the tongue—retroflexion. As a consequence, it is included amongst the retroflex (apico-post-alveolar) phonemes as they share a common place of articulation.

TABLE 1.1: *The Biniŋ Gun-wok consonant phoneme inventory after Evans (2003, p. 78) and Butcher (forthcoming).*

	PERIPHERAL			CORONAL		GLOTTAL
	BILABIAL	VELAR	ALVEOLAR	APICAL	LAMINAL	GLOTTAL
				RETROFLEX (APICO-POST-ALVEOLAR)	PALATAL (ALVEOPALATAL)	
LENIS	p	k	t	ʈ	c	ʔ
FORTIS	pː	kː	tː	ʈː	cː	
NASAL	m	ŋ	n	ɳ	ɲ	
LATERAL			l	ɭ		
RHOTIC			r	ɻ		
SEMI-VOWEL	w				j	

The two stop series, labelled lenis and fortis in Table 1.1, contrast in terms of length (Evans, 2003). It is assumed, based on consultation with speakers, that the difference in length of the consonants is phonologically contrastive and that duration is the primary cue to a phonetic difference between them. This does not imply that there is a difference in the actual force of articulation as the lenis and fortis labels would suggest. The phonetic correlates of the stop contrast and previous experimental research is discussed in further detail in § 2.1 and § 2.1.2. Evans (2003) proposes that long stops can be analysed phonologically in one of two ways, as either a long (or fortis) stop or as a homorganic cluster. There is debate as to whether these stops are realised with phonetic differences, however (see § 1.3.2, § 2.1 and § 2.2 for discussion of this debate in regard to definitions of fortis and gemination). If phonetic differences between fortis stops and homorganic clusters are found then these must be considered separately within a phonetic analysis. This is a key motivation for the current study which will allow further investigation into the phonetics of Biniŋ Gun-wok in general. By examining evidence for a differences in force of articulation and laryngeal setting between primarily lenis and fortis stops but also fortis stops and homorganic clusters it is possible to definitively separate the stop classes. This permits investigation of coarticulatory patterns of medial stops. Coarticulation in nasals is investigated in the final experimental chapter by examining anticipatory and perseverative patterns of coarticulation.

Butcher has suggested that the coarticulatory effects observed in vowels and the lack of coarticulation observed amongst consonants is due to an ‘imperative’ to preserve cues to the place of articulation of the surrounding consonants. This is achieved by maximising the retrievability of transitional information at the onset and offset of the consonant (Butcher, 2006a; Fletcher & Butcher, 2002, 2003; Fletcher, Stoakes, Loakes, & Butcher, 2007).

1.3.1 Vowels

Over half the languages of Australia have a phoneme inventory that contains only three vowels. The typical configuration consists of two vowels that contrast in the front and back dimension and a third that contrasts with the other two in the aperture dimension. This third vowel is usually a low central vowel (Butcher, 1994). The close front vowel is unrounded and the back vowel is rounded as is common cross-linguistically (Ladefoged & Maddieson, 1996, p. 292). There are very few languages recorded that contrast three vowels with only 5.4% of languages found in the UCLA Phonological Segment Inventory Database (UPSID) having this vowel phoneme configuration (Maddison, 1984, p. 127, cited by Butcher, 1994). Biniŋ Gun-wok has a five vowel system; a rich inventory by Australian standards (see Figure 1.2 on the facing page). Only 9% of Australian languages show this type of vowel system (Busby, 1980, p. 97f) although Butcher (1994, p. 28) considers this to be an underestimate. Five vowel systems are comparatively common vowel system amongst the languages of the world more generally. Vowel length is said to be entirely non-phonemic but there are some environments in which vowels in monosyllables are realised as long (Evans, 2003, p. 74). It has been suggested that the five vowel system found in Biniŋ Gun-wok is of ‘considerable antiquity’ based on phonological reconstructions of Proto-Gunwingguan (Evans, 2003). Biniŋ Gun-wok vowels have no phonological length distinction, but those in prosodically stressed positions are more prominent than unstressed vowels. Prosodically stressed vowels are usually realised with a longer duration and greater overall amplitude (Fletcher & Butcher, 2002).

Vowel systems across languages are thought to conform to a need to keep phonemes ‘sufficiently perceptually contrastive’ (Liljencrants & Lindblom, 1972). This has been called the ‘theory of adaptive dispersion’ which predicts that vowels will “...be dispersed maximally and evenly within the available phonetic space...” (Butcher, 1994, p. 28)—also see Lindblom and Maddieson (1988,

p.74). Disner (1984) gives a survey of the literature on the subject of vowel dispersion as part of an analysis of the UPSID corpus (Maddieson & Disner, 1984).

Australian languages do not exhibit vowels that are maximally dispersed within the acoustic vowel space however, although they are usually described with vowels that are evenly spaced and appear symmetrical within the space. Cross-linguistically, vowels are required to be far enough away from one another acoustically in order to provide a perceptual contrast with each other (Fletcher & Butcher, 2002). Consequently the vowel space of Australian languages is appreciably reduced, with vowels more centralised and consequently Australian vowel systems are described as having ‘minimal distinctiveness’ or ‘sufficient dispersion’ (Butcher, 1994; Fletcher & Butcher, 2002). In Bininj Gun-wok the five vowels are very centralised and Figure 1.2 shows that the /ɛ/ vowel phoneme is retracted and the /ɔ/ phoneme is advanced; in addition to these vowels being slightly raised phonetically.

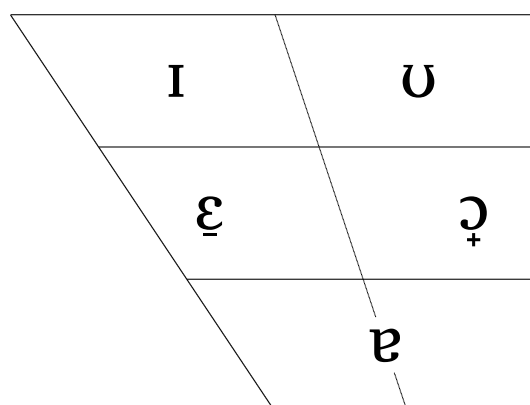


FIGURE 1.2: *The vowel phonemes in Bininj Gun-wok.*

As noted by Butcher for other Australian languages, the close vowel phonemes /ɪ/ and /ʊ/ are slightly lower than for the similar lax vowels in English. These vowels are more accurately described phonetically as the lowered mid-close front vowel [ɛ] and the raised and centralised mid-open back vowel [ɔ̟] (Butcher,

1994).

Although there are no phonologically long vowels in Bininj Gun-wok, there are eight phonetic diphthongs found in all varieties, although they are each phonetically slightly different. Evans (2003, p. 75) argues that they should be analysed phonologically as vowel plus semivowel rather than true diphthongs with multiple vowel targets. He says that the diphthong combinations “...represent all possible combinations of vowel with a following glide except for that of a high vowel with a glide of equivalent frontness” (Evans, 2003, p. 75). The phonetic realisations of the diphthongs with their equivalent orthographic representation in Bininj Gun-wok (Kunwinjku variety) are shown in Table 1.2.

TABLE 1.2: *Diphthongs in Bininj Gun-wok with relative prominence from Evans (2003).*

ORTH.	REL. PROMINENCE	EX. WORD	GLOSS
iw	[ɪʊ]	kundiw	‘liver’
ew	[ɛʊ]	mandewk	‘raincloud’
aw	[ɐʊ]	yawkyawk	‘young girls’
ow	[ɔʊ]	karnbowh	‘tree snake’
ey	[eɪ]	kunney	‘elbow’
ay	[ɛɪ]	yimray	‘tomorrow’
oy	[ɔɪ]	woybukki	‘true’
uy	[ʊɪ]	kuluybirr	‘saratoga’ (fish sp.)

There is some allophonic alternation between /e/ and /ɛ/ (phonologically non-high non-back) and also between /ɔ/ and /ʊ/ (phonologically non-high, back) vowels in some verb paradigms (Evans, 2003, p. 74).

1.3.2 Phonotactics

The morphological structure of Bininj Gun-wok makes the language a good candidate for the study of coarticulatory effects, particularly those involving place of articulation in clusters. Bininj Gun-wok is a highly polysynthetic language which exhibits 12 prefix slots on the verb and two suffix slots (Evans, 2003, 2004). Noun incorporation can occur within a wide variety of verbs which

means that a sentence can structurally comprise a single word which can be analysed as a verb. This generative characteristic of Bininj Gun-wok provides a wide variety of permissible consonant clusters that are available to a speaker in the course of vernacular speech.

Bininj Gun-wok prefers a CV(C) syllable structure according to Evans (2003, p. 89) and this gives a propensity for clustering at syllable boundaries. The high incidence of clusters within words and the observation that the long stop only appears word medially in bisyllabic words lends weight to an analysis of fortis stops in Bininj Gun-wok as homorganic clusters. Possible phonetic differences are investigated as they have been a matter of debate cross-linguistically (see Evans and Merlan (2004) for a survey).

In Bininj Gun-wok there are a number of phonotactic restrictions with respect to syllable construction that are highly relevant to this analysis. There are an unusually rich set of word/syllable final liquid plus stop clusters in Bininj Gun-wok when comparing it to other languages of the region. Coda clusters can have up to three elements if they are a liquid, nasal plus glottal stop ((L)(N)(?)), whereas the onset is restricted to a single segment. The more common configuration is to have a continuant followed by a stop, for example *kun.dulk*, ‘tree’. A representation of a simplified Bininj Gun-wok syllable structure can be expressed as:

(1.1)

$$C_i V(L) \left\{ \frac{(C_j)}{(N)(?) } \right\},$$

where C is any consonant except /?/, /V/ is a vowel, /L/ is a liquid (a lateral or a rhotic), /N/ is a nasal, and /?/ is a glottal stop. The subscripts *i*, *j* and *k* on the consonants indicate that they are possibly, but not necessarily, different places of articulation (adapted from Evans (2003, p. 90)).

The syllable structure in Expression 1.1 above, however, will generate many disallowed syllabic structures. To account for this over-generation, a revised

structure will be defined. This revised statement of allowable syllables is illustrated in Expression 1.2:

(1.2)

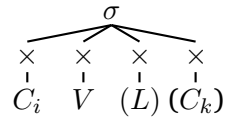
$$C_i V \left\{ \frac{(C_j)(C_k)}{(L)(N)(?)} \right\},$$

In Expression 1.2, $/C_j/$ is a non-occlusive consonant, for example a liquid or semi-vowel and $/C_k/$ is any oral stop. The optional structure is also shown where, $/L/$ is a liquid, $/N/$ is a nasal and $/?/$ is a glottal stop. These two syllable structures are mutually exclusive. The glottal stop only occurs when there is a liquid or nasal in the coda. The oral stops do not co-occur with glottal stops. If a syllable is not in word-initial position of a multisyllabic word, the alveolar trill $/r/$ —orthographically <rr>—is a possible syllable onset, but only when it appears intervocalically.

The following hierarchical structures show some possible realisations of Biniŋ Gun-wok syllables and these structures form the basis for constructing the experimental materials (see § 5.2.1). These syllable structures describe all possible Biniŋ Gun-wok words. When a word is bisyllabic—the most common syllable structure—there are very few restrictions to the place of articulation of the phonemes that cross a syllable boundary. Evans estimates 631 possible combinations of stops (Evans, 2003, p. 97). There is a notable restriction on clusters involving palatals, however as both apico-postalveolar (retroflex) stops and nasals and palatal stops and nasals do not form heterorganic clusters if the retroflex or palatal is in the coda position.

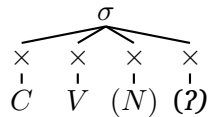
A very small number of coda clusters are not accounted for by the above expression but the internal structure of Biniŋ Gun-wok syllables will not be discussed further except to account for morpheme breaks in multi-morphemic words. Below are some proposed syllable structures for well-formed Biniŋ Gun-wok syllables.

(1.3)



Building on the structure shown in Expression 1.2, a proposed realisation for any Biniŋ Gun-wok $/C_iV(L)(C_k)/$ syllable is shown in the above expression and the proposed syllable structure for a syllable with a final glottal stop, $/C_iV(N)(?)/$ is shown in the expression below. Both diagrams illustrate that a Kunwinjku syllable can minimally consist of a consonant followed by a vowel but there are a number of optional elements that can also be included in a syllable coda. It should be noted that for most speakers a $/CV/$ monosyllable would have a phonetic glottal stop in the coda position. This has not been attested phonologically however, and could be a boundary marker (Baker, 2008) that appears as a result of recording words in citation form within a list (Carroll, 1976).

(1.4)



An important note on syllable structure is that although they obey standard sonority rules, there is a restriction on the position within the syllable that depends on place of articulation (Evans, 2003, p. 90). As noted by Hamilton (1996), there is a place of articulation hierarchy found within the phonologies of Australian languages—based generally on sonority. The phonemes found in onset and coda of syllables move leftward along the hierarchy in the order of labial $\rightarrow$ dorsal $\rightarrow$ laminal $\rightarrow$ apical. Dorsals are velar or uvular and articulated with the back of the tongue; laminals are articulated with the tongue blade; apicals are articulated with the tongue tip. This hierarchical organisation of the constituent phonemes within legal syllables is an important constraint in the phonology of Australian languages and as of yet there are no cross-linguistically phonetic studies that explore an articulatory motivation for this beyond the

accepted definitions of sonority and the tenuous relationship it has to syllable organisation.

The large number of possible consonant clusters found within Bininj Gun-wok make it an ideal candidate for the examination of interconsonantal coarticulatory effects. Additionally, the occurrence of complex syllable codas mean that Bininj Gun-wok is unusual when compared with other Australian languages (Hamilton, 1996). For a more detailed summary and explanation of the phonotactics and morphophonemics of Bininj Gun-wok, see Evans (2003). The richness in the number of allowable stop cluster combinations allows exploration of place of articulation dependent coarticulatory effects in the language, it also however means that recording all clusters is a prohibitively large task.

1.3.3 Two stop series in Bininj Gun-wok

In this study the members of the stop series, matched for place of articulation, are termed lenis and fortis (see above in § 1.3). The fortis stops are found in the middle of words whereas the lenis stops are found both word initially and word medially. There are many examples of stop clusters word medially and final stops are mainly unreleased and voiceless. Evans (2003) describes the stop contrast in Bininj Gun-wok and Top End languages more generally as a long/short alternation.¹⁴ Evans quotes Butcher (2004) who found acoustic duration to be the only reliable phonetic correlate of the contrast in languages of the Gunwinyguan and the Maningrida language families, a grouping proposed by Green (1987) (cited in Dixon, 2002). The Yolngu group of languages (Yolŋu Matha) also show a stop contrast in their phonologies and this is discussed further below.

In early research on Bininj Gun-wok—particularly the Kunwinjku dialect—Capell (1942) and Oates (1964) make no mention of a contrast in stop conso-

¹⁴The Top End is generally described as the northern section of the Northern Territory extending from the Joseph Bonaparte Gulf in the west, to the Gulf of Carpentaria in the east.

nants. In later descriptive literature on the related language Dalabon, Capell (1962) mentions ‘double’ stops but Sandefur and Jentian (1977), also working on Dalabon (Ngalkbun), does not include them in a phonological analysis of the language. Carroll (1976) too does not explicitly detail a phonological stop contrast within the stops, although he does refer to oral stops as being either geminate or non-geminate (Carroll, 1976, p. 13). Fortis stops are also not identified as phonologically contrastive in the word lists prepared by Carroll compiled to support his phonological analysis (1976, pp 21–24). Carroll (1976, p. 16) does refer to ‘oral stops with a glottalised release’, however, which he says is due to allophonic variation. Carroll also cites Capell (1967, pp 91–92) who mentions the possibility of “glottalised consonants other than stops”. Capell gives the example of the second syllable in the word *kunmilh*, ‘forehead’. He interprets the final syllable *milh* as either CVCC—if the glottal stop is a phoneme—or CVC if the ‘lh’ (/lʔ/) cluster is regarded as a single ‘glottalised consonant’. No other details are given regarding these glottalised consonants however. This example shows the intermediate status of the glottal stop. It may not be a segment with full phoneme status in the language and this matter is still subject to debate within the literature (Evans, 1995). Related to the distribution of glottal stops is the occurrence of clusters in the language. Evans mentions that there are “some tantalising similarities between the distribution of long [fortis] stops and of stop clusters when one examines their phonotactic distribution...” (Evans, 2003). Evans describes short [lenis] stops as positionally unrestricted whereas long [fortis] stops are restricted to intervocalic positions, with the possible exception of a non-occlusive consonant (i.e., liquid or glide) between the preceding vowel and the stop and the long stop must be non-apical or more generally non-coronal (see § 1.3.2 below).

The restricted distribution of fortis stops, particularly the observation that they pattern closely with heterorganic clusters, has motivated some researchers (for example McKay (1980)), to posit a geminate phonological analysis for lan-

guages with a stop alternation. These languages are analysed with a single stop series showing allophonic variation that is dependent on word position and resulting in gemination when they are part of homorganic clusters. Evans (2003) however, keeps a distinction between geminates and medial long-stops. He says that there is a phonetic difference between geminates and fortis stops that parallels morpheme membership in Bininj Gun-wok. Geminates are said to be homorganic clusters of stops with a morpheme boundary between them—created by means of reduplication, affixation or compounding—“Whereas phonemic long stops are realised phonetically as long, voiceless and tense” (Evans, 2003, p. 81). Evans goes on to say that phonetically “...geminated stops have a clear double articulation, with voice onset appearing roughly halfway through the combined closure period, though there may be some voicing throughout the entire closure.” (Evans, 2003, p. 81). This claim has not been verified instrumentally however, and a secondary aim of this study is to investigate differences between these two classes of long stop (fortis and geminate). The competing analyses of the two stop series and the advantages and disadvantages of each are investigated further in Chapter 4.

Evans further argues for keeping the geminates and fortis stops distinct on phonological and morphological grounds however;

[A]lthough there are suggestive resemblances in terms of phonotactics, between the distribution of long stops and sequences of two stops, these parallels are not complete and an ideal formal treatment should capture the phonotactic similarities without having to treat long stops as geminates (Evans, 2003).

Based on the phonological and morphological analysis posited by Evans, throughout this thesis, the fortis stop is analysed as a single phonological element. This leads to the question of whether a fortis stop is better analysed as part of the syllable onset, syllable coda or as ambisyllabic (see Catford’s defi-

nition of a geminate below in § 2.2). Evans has some observations about the distribution of long stops and has put forward some hypotheses as to their syllable licensing (Evans, 2003). Speakers of Bininj Gun-wok will not split long stops across a syllable boundary but will confine them to the syllable onset when repeating an isolated syllable (Evans, 2003). An example is found in the word *ku\$ku* ‘water’ with a velar long stop which according to Bininj Gun-wok speaker intuition is in the onset position of the second syllable.¹⁵ This is in contrast to a geminate that is created by morphological processes *dalk\$ken* ‘dingo’ which has the cluster split up. This second example may be an effect of the sonorant [ɬ] before the ⟨kk⟩ however. The root *dalk* constitutes a discrete morpheme with the meaning ‘grass’ and the differences between these two examples may be prosodic as argued by Baker (2008) for Ngalakgan (see § 4.1 below).

Below are some examples of words containing the proposed stop categories in Bininj Gun-wok. These are shown along with interlinear glossing to indicate the possible morpheme boundaries.¹⁶ In Example 1.5 a word containing a medial stop cluster described by Evans as a geminate is shown. In this example the homorganic cluster in the second and third syllable at the velar place of articulation spans a morpheme boundary (/k.k/) (see § 2.2 for more information regarding definitions of gemination).

- (1.5) bak -bak -ke
 ₁pek 'pek ke
 ‘break into pieces’.

Note that in the above example, the stress placement is on the penultimate syllable so the inter-morphemic cluster is in post-tonic position. The proceeding two examples show a medial fortis stops which does not span a morpheme

¹⁵The syllable boundary is denoted by the \$ symbol.

¹⁶See Appendix A.4 for the interlinear glossing conventions.

boundary. Evans (2003) regards these as single morphemes with morpheme internal long stops.

(1.6) bukkən
 'pʊk:ən
 'show'.

(1.7) bekkən.
 'pɛk:ən
 'listen'.

Heterorganic clusters such as those in Example 1.8 are abutting consonants articulated at different places of articulation. Due to the syllable structure in Biniŋ Gun-wok—as shown in Example 1.4 in § 1.3.2 on page 18—the heterorganic clusters are exclusively inter-morphemic clusters. There are however, fossilised morphemes that are not internally analysable. These so called 'cranberry' morphs complicate the analysis somewhat by providing an extra category.¹⁷

(1.8) kebkimuk
 'gɛbkimʊk
 'big nose'.

(1.9) badbong
 'pɛtpɔŋ
 'black rock wallaby (female)'.

The initial morpheme 'bad' in the word *badbong* 'female black rock wallaby' (Example 1.9) is an example of a cranberry morpheme (Evans, Pers. Comm.,

¹⁷Evans's rationale for using this term is that for most berry names you can break up the morphemes into individual words, e.g., strawberry into straw and berry, gooseberry into goose and berry, raspberry into rasp and berry and so on (after (Aronoff, 1976)). Cranberry however, cannot be parsed as there is no separate English word 'cran'. Kunwinjku has a number of these 'cranberry' morphs.

2007). The medial cluster of /d.b/ is separated by a morpheme boundary although the word *badbong* is also a single morpheme.

This analysis does not allow for intra-morphemic, heterorganic clusters and apart from the previously mentioned exceptions such as *badbong*. All syllables except for the small subset of cranberry morphemes can be analysed as a separate morpheme. This has significant bearing on the analysis, as the long stops are always morpheme internal and consequently can occur in the same word position as lenis stops whereas heterorganic clusters of stops—and by extension homorganic clusters of stops—occur across syllable boundaries. At the word level Evans (2003, p. 82) notes some further restrictions on the positioning of a fortis stop within a phonological word. Fortis stops are not found word initially, and they have a similar distribution to clusters of stops and nasals both heterorganic and homorganic.¹⁸

In summary, single intervocalic lenis stops and single fortis stops in medial position are intra-morphemic and are not analysed phonologically as part of a cluster. In contrast, any group of adjacent stops spanning a morpheme or word boundary, forms a cluster. Thus, in this analysis, a geminate is defined as an inter-morphemic homorganic cluster. The precise internal structure of these clusters is unknown, however. This does not follow the classical definition of geminates (see § 2.2 for some previous definitions of gemination).

1.4 Previous phonetic studies in Australian languages

In recent years there has been a marked increase in the number of recordings made as part of archiving and documenting Australian languages.¹⁹ Due to technical constraints however, very few detailed instrumental phonetics stud-

¹⁸I will be using the Kunwinjku orthography exclusively in this thesis (see Table A.1 in the Appendix A.8) as the majority of the language material presented in this thesis is drawn from this variety.

¹⁹Many of these recordings are archived at digital repositories such as AIATSIS or PARADISEC.

ies of Australian languages have been undertaken or reported to date. Capell (1967) was one of the first researchers to undertake a cross-linguistic phonetic survey of Australian languages and his conclusion was that there was greater diversity than first thought with much scope for further phonetic research. There are a growing number of phonetic studies, rapidly adding to the accumulated knowledge regarding the phonetics of Australian languages. Andrew Butcher and colleagues (Butcher, 1992, 1994, 1995, 1996, 1999, 2004, 2006a, forthcoming; Butcher & Harrington, 2003a, 2003b; Butcher & Loakes, 2008; Butcher & Tabain, 2004; Loakes, Butcher, Fletcher, & Stoakes, 2008; Tabain & Butcher, 1999a) have initiated and completed many detailed cross-linguistic phonetic studies of Australian languages, using a variety of instrumental and acoustic techniques from a variety of theoretical perspectives. These studies underpin the hypotheses central to the thesis.

More generally, there are a number of studies that examine the phonetic aspects of particular languages and compare these with languages from outside of the Australian continent. Anderson and Maddieson (1994) and Anderson (2000) are both detailed instrumental phonetic investigations into a small selection of languages. Anderson (2000) has a substantial perception component, which is particularly rare in the Australian context although this is rapidly changing (e.g. Bundgaard-Nielsen, Baker, Harvey, Best, & Kroos, 2012).

There are a number of studies regarding consonant articulation and coarticulation which investigate some of the hypotheses surrounding the place of articulation imperative found in Australian languages (Butcher, 2006a; Butcher & Tabain, 2004; Graetzer, 2007, 2012; Tabain, 2000, 2002, 2009, 2012; Tabain, Breen, & Butcher, 2003; Tabain & Butcher, 1999a, 1999b; Tabain, Fletcher, & Butcher, 2011). Phonetic studies of voicing and stop contrasts in Australian languages investigate some phonetic parameters related to voicing. Bradley (1980) has looked at voicing contrasts in the language Yanyuwa—a Non-Pama-Nyungan language spoken on the West of the Gulf of Carpentaria. There was

also a small study on the lenis and fortis contrast found in Jawoyn by Evans and Merlan (2004) and a phonetic study of a mixed language (Gurinjdi Kriol) by Jones and Meakins (2013). Phonetic investigations into the vowel systems of Australian languages show that in general they have relatively compact vowel systems (Butcher, 1994; Fletcher & Butcher, 2002, 2003; Fletcher et al., 2007; Tabain & Breen, 2011; Trefry, 1983). Additionally intonation and prosody is an area of phonetic research that has received much current work particularly in the northern Australian languages (Bishop, 2002a; Bishop & Fletcher, 2005; Fletcher & Evans, 2000, 2002; Ross, 2011) and also some investigation into Warlpiri intonation patterns (Pentland, 2004; Pentland & Laughren, 2004). In addition there is preliminary research on intonation in Pitjantjatjara (Tabain & Fletcher, 2012). There have been a number of illustrations of the IPA on Australian languages including Breen and Dobson (2005) and Bowern, McDonough, and Kelliher (2012). Tabain and Beare (2011) have also examined the spectral properties of bursts in Pitjantjatjara looking at spectral tilt measurements.

Many previous studies of the sounds of Australian languages have a phonological focus with initial phonetic investigations primarily reported to support the latter task of detailed grammar writing, documentation and language preservation. This is mainly due to constraints on time and resources; when drawing up a rapid sketch grammar time is short, and consequently some of the more subtle phonetic differences are necessarily lost when languages are regularised phonologically. Linguists often feel under-equipped in making phonetic transcriptions using only their eyes and ears (Maddieson, 2001). Once a phonology has been agreed upon it is challenging—even with access to large corpora of audio recordings—to impartially reanalyse the phonetics. Many phonetic studies compare Australian languages to Indo-European languages rather than considering them in the geographical context of Asia and Oceania. Further instrumental phonetic analysis is needed to describe not only the phonetic realisations that characterise unusual phonological contrasts but also those of

canonical articulations.

Australian languages, before European contact, had no explicit written language tradition and consequently alphabetic orthographies and phonemic inventories have only been recently devised by documenting linguists. This is usually, but not exclusively, done in close consultation with language speakers. The intuition of speakers of the language is most important in interpreting the phonology, but when a language has only a handful of speakers left this involved task becomes increasingly difficult. Many marginal or dying languages across the Australian continent and the world are in danger of disappearing before any substantial linguistic analysis is made (Evans, 2010). Of course this situation is not restricted to research into Australian languages but these issues are of particular relevance due to the monumental number of typologically distinct languages still in dire need of detailed description, many of which are heavily threatened with extinction. An emphasis on accurate phonetic recording is not seen as critical when studying languages with a rich written tradition. Usually there has been extensive prior phonological examination and it is possible to refer to the historical record for supporting evidence. For a language that is predominantly orally transmitted, as is the case in the majority of Australian languages, there are no such diachronic records. This means that it is not possible to reliably reconstruct with reliability the rapidity and extent of phonological sound change without thorough knowledge of the synchronic phonology of a language.

This thesis will seek to address many of these issues with a thorough phonetic description of a single Australian language, Bininj Gun-wok. I will show where Bininj Gun-wok conforms with, and departs from, prior phonological models of related Australian languages and languages of the world with special reference to medial consonants.

1.5 Hypotheses and research questions

Previous linguistic descriptions of Biniŋ Gun-wok have classified two stop series that contrast in terms of length (discussed above in § 1.3.3). Is this the only difference between them however? In addition to length is there any indication that there is a difference in strength between them, justifying the *lenis* and *fortis* labels? If the *fortis* stops do form a separate phonological category, are there any consistent phonetic differences evident between *fortis* stops and geminate clusters, when the articulatory evidence is considered? Finally, is there evidence of a delay in nasalisation that serves to preserve place of articulation cues in Biniŋ Gun-wok?

Each of these questions are investigated and hypotheses developed to allow them to be tested experimentally. The hypotheses are states below and further research questions and hypotheses that came out of the review of the literature are presented in greater detail in § 4.5 at the conclusion of Chapter 4.

1.6 Organisation of the thesis

This study comprises three discrete experiments that examine in detail various aspects of stop and nasal consonant articulation in Biniŋ Gun-wok. The literature that details the linguistic more specifically phonetic research that support these experiments is presented in Chapter 2, Chapter 3 and Chapter 4.

Chapter 2 provides the background to discussing consonants and the phonetic structures comprising them with a focus on the phonetic correlates of fortition. Chapter 3 looks at nasals and coarticulation. Chapter 4 describes contrasting consonant series within the context of Australian languages. An outline of previous experimental research regarding consonants in Australian languages and how these results differ from those found in other languages of the world is presented in § 2.1.2 and 4.1.1.

Previous literature on the stop contrast found in various Australian Lan-

languages including Bininj Gun-wok is summarised in § 2.1 and § 4.1. The concluding section of Chapter 4, § 4.4, provides a summary of previous research into the phonetics of Bininj Gun-wok consonants, describing some observed facts about articulation. In chapter 4, informed by the current literature of the field, The methodology is presented for each of the three experiments.

The experimental chapters at the core of this study are found in chapters 6, 7, 8 and 9. The first three of the chapters summarise two experiments that examine stops in a word medial position.

The first experiment is reported in Chapter 6 and is a quantitative analysis of the acoustic phonetic properties of oral stop consonants. The second experiment is divided into two parts that examine a selection of the physiological aspects of medial stop realisation. The first part of the experiment, reported in Chapter 7, is an analysis of the aerodynamic properties of stops which are correlated with the results of the acoustic analysis in Chapter 6. The second part of experiment two looks at possible differences between fortis stops and geminate stops comparing duration, aerodynamics and introducing a voicing analysis. These results are reported in Chapter 8. The results include a comparison of the durations of homorganic clusters and heterorganic clusters is (reported in § 8.2.1).

The medial position is site of the majority of phonetic contrasts within Bininj Gun-wok and the unifying theme of the thesis is an examination of this position within the word. Many words in Bininj Gun-wok involve word medial clusters containing sonorants. Sonorants are prevalent amongst Australian languages and the final experimental chapter (Chapter 9) turns the attention to nasal consonants and oral and nasal consonant clusters. The directionality of coarticulation of nasalisation in Bininj Gun-wok is investigated using both acoustic and aerodynamic techniques. The concluding chapter (Chapter 10) summarises the results of the experimental chapters and possible phonological implications.

Chapter 2

Consonants: length, strength and voicing

This chapter surveys previous experimental research on consonants, primarily in languages from outside of Australia. The role of instrumental phonetic analysis in shaping our understanding of the phonetic structures of these languages is explored. Definitions of terms used in the phonetic description of consonants and the associated connected speech processes are introduced. The following chapter (Chapter 4) surveys previous phonetic research on both consonant articulation and how the terms *lenis* and *fortis* apply to Australian languages. A *fortis* consonant is somehow stronger than a *lenis* consonant, but how to define auditory or articulatory strength is problematic as there is no single phonetic parameter or universally agreed upon group of parameters differentiating a *lenis* and a *fortis* category.

2.1 Fortis and lenis

A consistent cross-linguistic phonetic definition of *lenis* and *fortis* stops has thus far been elusive (Butcher, 2004; Cho, Jun, & Ladefoged, 2002; DiCanio, 2012; Hardcastle, 1973; Kohler, 1984; Ladefoged & Maddieson, 1996; Malécot,

1970). Current research shows that no one phonetic parameter is sufficient to describe observed differences between the contrastive categories lenis and fortis. Early writing on this subject mostly describes lenis and fortis obstruents as contrasting for strength or effort, with the fortis segment articulated with greater ‘effort’ than its lenis counterpart. What is meant by effort, however, has not been fully defined despite many attempts to quantify the contrast.

Tension within the speech system has been invoked as a key phonetic difference between stop types across languages and it could be assumed that greater tension equals greater effort. A feature ‘tense’ is described as being functionally equivalent to fortis and ‘lax’ equivalent to lenis. These are often based on inferred differences in laryngeal tension between two classes of stop described in a number of languages. In the literature however, the terms tense and lax have had a wider definition involving a large set of phonetic parameters. Hardcastle (1973, p. 263) lists some of the previous research that discusses the tense/lax distinction and shows that there is little agreement on the acoustic or physiological correlates for the [$\pm$ tense] phonological feature. Some possible phonetic correlates are peripheral tongue position (Jones, 1918; Sweet, 1906), width of the pharynx (Perkell, 1969), position of the larynx (Ladefoged, 1964), intra-oral pressure (Malécot, 1970; Stetson, 1951), the formant structure—described by ‘sharpness’ or ‘distinctiveness’— (Han & Weitzman, 1970) and duration (Fischer-Jørgensen, 1968; Jakobson & Halle, 1962). All of these studies contend that a single feature signals a distinction between the stop types. Lisker and Abramson (1964) argue for a group of parameters rather than relying only on [$\pm$ tense] as a cue to the difference. They go on to say that all phonetic known correlates of fortis and lenis are “...significantly correlated with voicing or aspiration” (Lisker & Abramson, 1964, p. 385–6, cited in Hardcastle (1973)). This observation was the rationale behind combining voicing and aspiration into a bundle of parameters which termed voice onset time (VOT) (Lisker & Abramson, 1964). and it is argued that VOT can describe

differences between stop types with more accuracy than degrees of tenseness. VOT is defined as the duration between the release of the articulators and onset of regular voicing in consonants and is discussed in more detail below in § 2.3.

Kohler (1984) also refers to multiple parameters underlying the lenis/fortis contrast. He points to both “... an articulatory timing and ... a laryngeal power/tension component. The former relates to the speed of stricture formation and release, and is probably a language universal, the manifestation of the latter aspiration, voicing, glottalisation is language-specific” (Kohler, 1984, p. 168). Ladefoged and Maddieson (1996) offer a couple of possible definitions: fortis is either an indicator of increased respiratory energy or alternatively, fortis is an indicator of greater articulatory energy, although these need not be mutually exclusive. The lenis counterpart indicates less energy in the corresponding member of the pair. The use of increased respiratory energy is rare cross-linguistically and occurs in the case of Korean ‘stiff’ voice (now more commonly labelled with the term ‘fortis stop’)—in which a heightened sub-glottal pressure accompanies a more constricted glottis and tenser walls of the vocal tract. Korean lenis and fortis initial stops will be discussed further below in § 2.1.1.

It is clear that fortis and lenis are terms with phonetic correlates that are not agreed upon cross-linguistically. They do however signal a phonological contrast that may have a number of cues associated with it, some of which may be language specific. What seems clear from previous research is there is no single correlate of lenis and fortis across all languages. This study will look at how lenis and fortis stops are phonetically realised in Bininj Gun-wok and will utilise a combination of airflow measurements, and an investigation into the co-ordination of laryngeal timing across multiple speakers of the language.

2.1.1 A cross-linguistic survey of an attested lenis/fortis contrast

Detailed instrumental investigations into the phonetics of lenis and fortis stop contrasts across languages are relatively few and these labels are often used to describe stop contrasts in languages instead of using terms such as voiced and voiceless. These terms are very common in the descriptions of the Germanic languages—German, English and Dutch—and they are widely used in descriptions of American English (Jansen, 2004; Ladefoged & Maddieson, 1996).

There are very few languages in which stops differ only in terms of articulatory strength rather than with additional voicing or laryngeal timing contrasts. A subset of Northern Caucasian languages have consonants described as a strength contrast in between stops that is independent of voicing. Ladefoged and Maddieson (1996, p. 97) cite a number of studies on Dagestanian languages including Tabasaran (Kodzasov & Muravjeva, 1982), Archi (Kodzasov, 1977) and Agul (Aghul), (Kodzasov, 1990). Ladefoged and Maddieson (1996) argue that after examining available recordings duration should be considered as the major cue to a difference between the categories. The longer stops are formed from two homorganic single consonants that span a morpheme boundary (see § 2.2). They also note that some dialects of Aghul have a large number of initial long (or fortis) stops. Maddieson (1999b) examined fricatives in these languages and found that in these obstruents the phonemic difference was cued by differences in strength rather than closure duration.

A language that has been extensively studied with regard to voiceless word initial consonants is Korean particularly the Seoul variety (for example, Abber-ton, 1972; Abramson & Lisker, 1971; Cho & Jun, 2000; Cho et al., 2002; Cho & Keating, 2001; Dart, 1984, 1987; Han & Weitzman, 1970; Hardcastle, 1973; Hirose, Lee, & Ushijima, 1974; Kagaya, 1971, 1974; Kim, Hirose, & Niimi, 1992; Martin, 1951; Shin, 1994).

The bulk of the instrumental investigations into Korean stop articulation have focussed on word initial consonants most commonly described today as

aspirated, lenis and fortis. The contrast is present in obstruents—oral plosives and a small set of fricatives. The fortis and the lenis obstruent categories have been described as forced and lax (Hirose et al., 1974) or as tense and lax (Cho et al., 2002).

The research on Korean has informed much of the current phonetic literature on strength of articulation and Korean is still one of a very small set of languages, including the previously mentioned Dagestanian languages, that is categorically said to have true lenis and fortis articulations (Ladefoged & Maddieson, 1996).

As noted by Dart (1987, p. 139), in Korean there are other phonetic factors in addition to the state of the glottis that influence the values of intra-oral pressure and oral air flow. These include changes in sub-glottal pressure, tension in the vocal tract walls, and active expansion of the vocal tract. Some of the contrasting articulatory features are summarised in Table 2.1 below, from Kim and Duanmu (2004, p. 64). The table summarises many of the phonetic differences between the tense and lax stops.

TABLE 2.1: *The differences between “tense and lax” in Korean.*

	Tense	Lax
Following tone	higher	lower
VOT	shorter	longer
Glottal opening	narrower	wider
H1-H2 (breathiness)	smaller	larger
Intensity	strong	weak
Voicing duration	shorter	longer
Airflow at release	smaller	greater
Air pressure before release	greater	smaller

The main acoustic differences are associated with VOT, which is directly related to aspiration. A further measurable difference is in the microprosodic changes of F_0 at the release of the stops. This is related to laryngeal tension and has been shown to be consistently higher after voiceless stops (Ohde, 1984, see Table 2.2). The main articulatory differences between the categories are due

TABLE 2.2: *Acoustical features of “tense and lax” stops in Korean.*

Manner	Tense	Lax	Aspirated
Aspiration	Unaspirated	Slightly Aspirated	Heavily Aspirated
VOT	10ms after release	Longer than tense but no overlap	2–5 times longer than lax
F0	Generally higher in following segment		
Amplitude of voice onset		Significantly lower	
Manner of voice onset	Abrupt	Gradual	Intermediate
Formant structure	F3 and F4 prominent	weaker higher formants	
Speech wave form	Symmetrical (less damping)	more damping	

TABLE 2.3: *Articulatory features “tense and lax” stops in Korean.*

Manner	Tense	Lax	Aspirated
Glottal width at oral release	narrow but not closed	moderately open	wide open
Glottal activity	Closes rapidly with complete contact of the vocal processes		
Tongue contact for apicals	Greater	Less	Greater
Muscle activity in lips for labials	Greater	Less	Greater

to differing glottal apertures and timing (see Table 2.1 and 2.3). Do lenis and fortis stops in Biniŋ Gun-wok follow similar patterns to the languages described above, including Korean? This is not clear from the previous experimental literature into these languages. For this reason, many of these parameters, both acoustic and articulatory, will be investigated in the experimental chapters on stops where data are available for Biniŋ Gun-wok (Chapters 5, 6 and 7).

2.1.2 Experimental studies: fortis and lenis

In Korean, a difference in VOT for stops in initial position was reported by Lisker and Abramson (1964) for the aspirated stop phoneme when compared with the two unaspirated phonemes. VOT alone was not sufficient to describe differences between lenis and fortis stops. The measurement of VOT is discussed further below in § 2.3. Aerodynamic and articulatory studies on various languages (Abberton, 1972; Dart, 1987) show that a greater intra-oral pressure is measured in fortis stop articulations generally and this is due to increased *respiratory* effort and tenser walls of the vocal tract. Hardcastle (1973) looked at the tense/lax (fortis/lenis) distinction in initial Korean stops and found that each of the stop types had a different glottal profile. Kagaya (cited by Hardcastle, 1973), found that the glottis was tightly closed immediately prior to vowel onset in the tense stops, slightly adducted for the lax stops and wide open for the strongly aspirated stops. Kagaya (1974) revises the previous assertion that the glottis is closed immediately prior to voice onset in fortis stops and says tense (forced or fortis) stops have a narrow glottal configuration but not one that is fully closed (adducted). This discrepancy may be due to the limitations of the measurement devices used in the study or alternatively due to speaker specific factors. It should be noted that each of these studies use a single male speaker of Korean (Kim et al., 1992). Prosodically, there is evidence that, both word initially and phrase initially there is greater articulatory strength. This has been measured experimentally using aerodynamics and electropalatography (Cho & Jun, 2000; Cho et al., 2002; Cho & Keating, 2001). The idea that there is some kind of strengthening in domain initial positions will be discussed in greater detail below.

The Dravidian languages—varieties of Tamil (Keane, 2004; Master, 1939; Narayanan, Byrd, & Kaun, 1999; Zvelebil, 1970) and Malayalam (Dart & Nihalani, 1999; Local & Simpson, 1999)—have alternations between a number of stop series including implosives as well as long and short stops. Fraser (n.d.)

proposes that so called double stops in Tamil are tense “...in a way that is similar to—though not identical to—those of Korean”. It is also proposed that the glottis is closed during these double stop articulations. There is limited support for this assertion with reference to electroglottographic results, but this is unfortunately only a preliminary investigation. Also in Tamil, Keane (2004) says that duration may not be the only factor in differentiating singleton and geminate stops. Keane makes no further comment as to whether geminates can be described as a second, distinct stop series—as proposed by Fraser—or whether there is any difference in glottal configuration for the durationally longer stops. It is interesting to note that Tamil is very similar phonetically to the majority of Australian languages in that there are more place of articulation contrasts and fewer manner of articulation contrasts in its segmental phonology. This fits with the ‘long-thin’ or ‘long-flat’ phonologies described by Butcher (2006a) in Australian languages (see the discussion above in § 4.3).

DiCanio (2008, 2010, 2012) has investigated correlates of strength of articulation for lenis and fortis stops in Itunyoso Trique, a language spoken in Mexico. Trique, a member of the Oto-Manguean group of languages, is related to Zapotec, which has been previously compared to the Australian language Jawoyn by Jaeger (1983). The two stop series in Jawoyn are in a lenis vs. fortis relationship (Jaeger, 1983). DiCanio found that the contrast between the stop series is one of length with an added glottal width feature and “...for obstruents, the duration of voicelessness is a consistent correlate of the contrast, rather than simply the closure duration” (DiCanio, 2008, p. 133). DiCanio (2008, p. 133) found that by using acoustic measures there was no evidence “...to support an analysis of the contrast in terms of consonant strength or articulatory effort”, for example (Jansen, 2004; Kirchner, 2000; Kohler, 1984).

Vowel length is associated with the perception of whether a stop is voiced or voiceless. The observation that a vowel preceding a voiced consonant is longer than the vowel before a voiceless consonant is considered a phonetic universal

and has been investigated by Port and Dalby (1982). They found in a perceptual study of American English that the vowel length contrast before consonants is partially independent of the voicing contrast and in addition it is restricted to stressed syllables. This length effect has been termed pre-fortis clipping in English by Wells (1990). The effect is reported to be far greater however, in English than for other languages (Maddieson, 1999a). Research has also shown that additionally, long consonants—which are often but not always voiceless—have a shorter preceding vowel duration. Furthermore, “[o]bstruents which are [+tense] are realised with a shorter preceding vowel and a long closure duration while [–tense] obstruents are realised with a long preceding vowel and a short closure duration” (DiCanio, 2008, p. 88). If a vowel is always shorter before each of these phones, could they all be different names for the same type of articulation? This could also be a result of coarticulation between the two adjacent phones. Differences in vowel length effects before medial consonants in Bininj Gun-wok are investigated and reported in § 6.6.

2.2 Geminates

In this study it is hypothesised that fortis stops form a discrete phonological category with a distinct set of phonetic cues that are separate to those of lenis stops. In Bininj Gun-wok, clusters of stops occur in a very similar distribution to fortis stops and consequently on the surface it is difficult to observe a difference between homorganic clusters and long stops. One key difference between them however, is that fortis stops are long stops which are morpheme internal whereas homorganic clusters arise due to morphological gemination; when two abutting stops belonging to separate morphemes come together. In Bininj Gun-wok, the placement of a morphological boundary makes it difficult to class these homorganic clusters according to classical cross-linguistic definitions of geminates. Geminates are traditionally thought of as word internal and, due

to Bininj Gun-wok's complex polysynthetic morphology, the word domain is not clear cut. These groupings will be considered in further detail below with respect to Australian languages with a contrasting stop series, as it has been a fertile point of discussion within the Australian linguistic community (see § 4.1 for further details). Prior to that, cross-linguistic definitions of gemination will be discussed.

There has been debate amongst phonologists for over a century as to whether a geminate is realised in the same manner as a long stop (Lehiste, 1970; Lehiste, Morton, & Tatham, 1973). The term geminate is often used interchangeably with long voiceless stops by many researchers—for example Sadanand (1992)—and a strict phonetic definition of a geminate is difficult to find. Many definitions share much in common with those for lenis and fortis consonants. A commonly accepted definition of gemination is that a geminate is a single melodic unit associated with two prosodic positions (Clements & Keyser, 1983).

It should be noted that Catford (1977, p. 210) reserves the term 'geminate' exclusively for tautomorphemic, ambisyllabic consonants, although it is noted that phonetically long consonants may be ambisyllabic or tautosyllabic and heteromorphemic or tautomorphemic. This is similar to the description provided by Blevins (2004) between 'true' and 'false' geminates, but both true and false geminates "... may be characterized by a single articulatory gesture or two distinct articulatory gestures" (Blevins, 2004, p. 170).

Morpheme internal geminates and geminates which arise via assimilation are true geminates, and ... in all languages with an underlying consonantal length contrast, true geminates contrast with non-geminate consonants. False geminates arise via morpheme concatenation (without obvious assimilation), and can occur in languages, which lack underlying length contrasts (Blevins, 2004, p. 170).

Geminates are said to be associated with certain phonological properties

such as a resistance to both epenthesis and lenition and also to a number of diachronic processes (Blevins, 2004). Synchronic processes that form gemination are common amongst the languages of the world but there is significant debate as to the phonetic correlates of gemination. Phonetically, stops with a higher duration are more likely to be voiceless and if there is an associated increase in duration of the occlusion phase this makes voicing more difficult to maintain (Westbury, 1983). There are however many examples of languages with voiced geminates (Ridouane, 2007).

Ridouane (2008), in a thorough survey of phonetic studies on geminate consonants, found that there is a central theme common to them all, namely that the only consistent phonetic correlate shared by geminates across languages is a significantly longer measured duration when compared with singletons in the same language (Ridouane, 2008, p. 6). Following on from Blevins (2004). Ridouane (2008) also identifies two types of geminates in Tashlhiyt Berber. The distinction is made between phonologically derived geminates and lexical geminates and he goes on to describe them as ‘fake’ and ‘true’ geminates. “True geminates, including lexical and assimilated geminates, are phonetically implemented by additional correlates, which account for the ‘strength’ displayed by these segments” (Ridouane, 2008, p. 27).

Keane (2001, p. 158), says that, contrary to what is found in the phonological literature, there is “...ample support in the phonetics literature...” for duration *not* to be the primary cue to gemination (see further discussion below). Keane cites Cohn, Ham, and Podesva (1999), for an investigation in Toba Batak, and Louali and Maddieson (1999) for Berber, both of which involve lenition of single segments and factors beyond simply duration. Particularly in the case of Berber, a distinction between single and geminate is the result of a spirantization process which is now contrasts fricative and plosive rather than length (Louali and Maddieson, 1999).

Bininj Gun-wok fortis stops conform to Catford’s (1977) second criterion for

the definition of a geminate (see above). Fortis stops are tautomorphemic but there is debate as to their syllabic licensing as there are restrictions on their position within a syllable so they cannot be definitively analysed as ambisyllabic (see § 1.3.2). According to the description of geminates given by Blevins (2004) above, Bininj Gun-wok contains both ‘true’ and ‘false’/‘fake’ geminates. The ‘true’ geminates are congruent to the fortis stops and the ‘false’ or ‘fake’ geminates to homorganic inter-morphemic stop clusters. In the experimental chapters (Chapter 6 and Chapter 7, differences in the phonetic articulation of fortis stops and the putative class of “false” geminates are compared to investigate any differences in strength that may be evident between them.

Gemination is very common cross-linguistically. Some examples of gemination explicitly recorded in their phonologies include: Italian (Stevens, 2007), Finnish (Doty, Idemaru, & Guion, 2007), Cypriot Greek (Arvaniti, 1999; Arvaniti & Tserdanelis, 2000; Tserdanelis & Arvaniti, 2001); languages of the Indonesian archipelago (Cohn et al., 1999); varieties of Arabic (Ham, 1998); Persian (Hansen, 2004); varieties of Berber (Applegate, 1958; Ridouane, 2003, 2007; Ridouane, Fuchs, & Hoole, 2006; Saïb, 1974, 1977), Hungarian (Ham, 1998), Guinaang Bontok a language spoken in the Philippines (Aoyama & Reid, 2006); Japanese (Hirose, Yoshioka, & Niimi, 1979). There are also a number of languages of the Indian subcontinent that show phonologically long stops, particularly the Dravidian languages such as Malayalam (Local & Simpson, 1988, 1999), Kannada and Tamil (Balasubramanian, 1972; Fraser, n.d.; Keane, 2001).

Many quantitative phonetic studies looking at the durational aspects of geminate articulation go further and examine non-durational aspects of the languages. Lehiste et al. (1973), when looking at geminates in Estonian and American English, found that there was indeed a difference between long stops and geminates in articulatory terms if not in durational terms. Using electromyographic and intra-oral pressure measurements they show that there is clear re-articulation in the geminates that span word boundaries in utterances

by a native speaker of Estonian. This effect is transferred when the same speaker produces utterances with word medial geminated clusters in American English.

Lahiri and Hankamer (1988)—in a study of Turkish and Bengali geminates restricted to intervocalic voiceless stops—investigate whether heteromorphemic long consonants differ from tautomorphemic long stops in both the phonetic and phonological domains. They use the term ‘geminate’ to denote a phonetically long consonant regardless of its morphological licensing. The results of the study show that duration of closure is the only consistent difference. There were however other differences observed separately for each language. A difference in VOT was found for Turkish whereas in Bengali the difference was in vowel duration. This study uses a similar definition of geminate in the analysis.

Delattre (1971a) researched both acoustic and articulatory aspects of geminates in English, German, Spanish and French using radiography. He uses the term gemination to describe “...meaningful perceptual doubling of a consonant phoneme” which “occurs frequently across [a] word boundary” (Delattre, 1971a, p. 31). He did not find that vowel duration reliably distinguished geminates from singletons but he did find that duration was not the only difference between them and a geminate has two distinct articulatory phases that have some characteristics of initials and some of finals. Hansen (2004) focussed on speaking rate and the effect that had on geminate duration in Persian and also found that C/V ratios did not reliably discriminate between geminates and singletons. There was a clear durational difference between them but speaking rate did influence the durations. Modarresi (2002) investigated coarticulatory patterns in Persian focussing on geminate and singleton consonants. Amongst other techniques he used locus equations to measure levels of coarticulatory resistance and compared these results to English (see § 3.2.3). He found that “[l]ower slopes (tongue body displacement effects) were observed in closed versus open syllables and with voiceless versus voiced stops” (Modarresi, 2002, p. 224) although it is noted that the results were unclear and this may be due to

the specific methodology. Geminate consonants are not restricted to the word medial position. Word initial geminates are found in a number of Austronesian languages, for example Patani Malay (Abramson, 1986, 1987, 1991, 2003). These initial geminates are also found in the related language Kelantan Malay spoken across the border of Thailand in Malaysia (Hamzah, 2013; Hamzah, Fletcher, & Hajek, 2011, 2012; Hamzah, Hajek, & Fletcher, 2012). These initial geminate consonants are phonologically long stops with a longer duration than their singleton counterparts and they have been formed via a grammatical process and create a grammatical distinction within the language.

Generally, it is still unclear whether closure duration is the only way in which geminated stops can be differentiated from fortis stops in a language. Are they phonetically identical despite the differences in phonologic structure? Experimental evidence suggests that there are measurable differences although many of these differences may be language specific based on the higher order linguistic structure. Further discussion on this topic with regard to Australian languages is introduced below in § 4.1.

2.3 Voice onset time

Many languages use a combination of phonetic cues to signal differences between phonological stop categories. To ensure that there is a maximal phonetic distinction between stop types, phonetic parameters of timing and manner are controlled. Lisker and Abramson (1964), in their comprehensive and important cross-linguistic study of timing in stops, found that the group of timing events they term voice onset time (VOT) was a highly effective means of separating phoneme categories.

Lisker and Abramson (1964) also note that phonetic voicing is often used to distinguish stop types within a language. Whether some sort of ‘glottal buzz’ is audible during the closure phase is an adequate cue for separating stop cate-

gories in many languages (Lisker & Abramson, 1964, p. 384). Languages such as English exhibit a voiced/voiceless stop distinction in word medial position, but in word initial position the stops are realised as voiceless. It is for this reason that the extra phonetic dimension of aspiration is needed in combination with voicing to describe stop contrasts in English. Voicing, aspiration and ‘force of articulation’ were taken as independent parameters and due to this work there are grounds for considering differences in their realisation as a consequence of a single underlying variable.

They propose using VOT as a phonetic basis for distinguishing between phonemic categories and posit some possible categories. These are, voicing lead, short voicing lag and long voicing lag. VOT can be thought of as the acoustic correlate of laryngeal timing. VOT refers to the temporal relation between the release of the stop occlusion and the onset of glottal pulsing (Hardcastle, 1973, p. 263).

Subsequent to Lisker & Abramson’s (1964) original publication, Abramson (1977, p. 295) makes some further points about VOT. The first is, that extensive use of physiological data that gave information about the larynx was difficult when the VOT measurement was first proposed. This meant that the choice was made to use the more readily available acoustic signals. Specifically, “[T]he most convenient acoustic index to the closing of the glottis for phonation in initial position was the beginning of regular vertical striations corresponding in a wide-band spectrogram to the quasi-periodic voice pulses of speech” (Abramson, 1977, p. 295–6). For this reason VOT alone cannot be used to differentiate stop types in all languages as there needs to be an articulatory component to any complete description of stops.

Cho and Ladefoged (1999) summarise cross-linguistic VOT data in addition to the languages first reported by Lisker and Abramson (1964). They detail a number of principal findings of previous VOT studies.

1. “The further back the closure the longer the VOT (Fischer-

Jørgensen, 1954; Peterson & Lehiste, 1960).

2. The more extended the contact area, the longer the VOT (Stevens, Keyser, & Kawasaki, 1986).
3. The faster the movement of the articulator, the shorter the VOT (Hardcastle, 1973).” (Cho & Ladefoged, 1999, p. 208).

Cho and Ladefoged (1999) concentrate mainly on the velar place of articulation and identify four categories for VOTs across languages, which they term unaspirated, velar stops with a mean VOT of around 30 ms; slightly aspirated, velar stops with a mean VOT of around 50 ms; aspirated with a mean VOT 90 ms; highly aspirated, with a mean VOT in excess of 90 ms.

VOT has been criticised as an appropriate way to differentiate and group stop types across language (for example Rothenberg, 2009). If VOT is a valid group of features is it adequate to classify stop types within languages? Kim (1970) argues that the single-feature VOT measure is insufficient for stop description in many languages. Rothenberg (2009) in particular has criticised VOT as a sole measure of differences between stop types and has said that although it was a useful parameter in speech synthesis for English it is problematic when used as a descriptor for “actual spoken language” (Rothenberg, 2009, p. 1). Rothenberg goes on to say that without articulatory measurements there are not sufficient parameters required to complete the picture for many stop contrasts in natural language.

Docherty (1992) questions the value of rigid phonetic categories such as voicing, aspiration and VOT when looking to classify stops. He says that presenting VOT values together with the relevant phonological contrasts is much more useful in fully describing spoken language. Scobbie (2006) says that this may be particularly true of languages that do not have a phonological voicing contrast, including those in which phonetic voicing is contextually conditioned. This describes Australian languages well and Scobbie (2006) goes on to say,

“[o]ne of the major outcomes of Cho and Ladefoged’s paper is that there are no clear demarcations in VOT to classify such stops in a universal or deterministic way” (Scobbie, 2006).

Despite these repeated criticisms of VOT as a way of describing both degree of aspiration and also distinguishing between stop types, VOT persists as one of the most commonly reported measurements recorded in the literature. This is particularly true of studies of Australian languages, but Jones and Meakins (2013, p. 197) note, that there are very few studies of VOT in Australian languages and of these the majority are of languages with two stop series (such as Bininj Gun-wok) rather than those languages that do not have a phonological voicing distinction. In addition, the most commonly reported VOT measurements in Australian languages are those using data from medial stops. In contrast Lisker and Abramson (1964) base all of their VOT measurements on that of initial stops.

It is now the general consensus that VOT alone is not a reliable way of pointing to differences in stop type and aspiration. It has been shown experimentally however, that VOT *does* reliably distinguish place of articulation in many languages. This highlights the articulatory reality that each of the articulators moves at a different rate and consequently each place of articulation is realised with different inter-articulator timings.

Voice onset for both initial stops and medial stops in stressed syllables is readily measured using acoustic methods. Using a spectrogram generated from an acoustic signal it is possible to identify the release burst (seen as a transient or spike) and the subsequent onset of regular voicing in the following vowel and the resulting VOT. Acoustic measurements have many advantages over articulatory recordings, the main benefit is that both new and existing recordings can be quickly annotated and analysed. The main disadvantage is that even low levels of background noise in field recordings can make VOT measurements difficult. This is most evident in stops with negative VOT values (short and long

lag).

An over reliance on VOT measurements to describe the complex continuum of laryngeal activity in stop articulation has been noted even by Abramson himself (Abramson, 1977, pp 296–7). He suggests that it is more useful to study differences in voice timing or more specifically laryngeal timing and that “... laryngeal timing is a powerful differentiator of homorganic consonants” (Abramson, 1977, p. 297). Lisker (1978) makes the observation that VOT is only one of several ways to express the timing relationships between the laryngeal and supralaryngeal gestures that are produced in consonant articulations. VOT seems to remain viable however as a method for differentiating between stop series relatively well in English and a number of other languages (Lisker & Abramson, 1964).

VOT has been shown to be insufficient to describe voicing contrasts between stop categories in Gurindji Kriol, a mixed language spoken in Northern Australia, as reported by Jones and Meakins (2013). There will be more discussion of this study of consonants contrasts in an Australian language and other studies of VOT and voicing contrast in the following Chapter (§ 4.1.1).

VOT measurements are presented in the current study by way of a comparison to other previous work on timing and voicing in stops. Also VOT as a way of differentiating place categories is also investigated. Previous discussion of whether there is indeed a difference between the VOT of stop categories in Bininj Gun-wok is discussed in Chapter 6 specifically in § 6.5.1.

2.4 Voicing, aerodynamics and laryngeal tension

Differences in voicing are a major cue to the phonological categorisation of stops, yet in the majority of Australian languages it is assumed that voicing does not play a major role in distinguishing between stop categories.

Controlling the rate and volume of airflow is fundamental to speech. Voic-

ing can only be initiated and maintained if the aerodynamic conditions are right. “In order for voicing to occur there are two basic requirements: first the vocal cords must have the appropriate degree of tension and the appropriate degree of adduction and, second, there must be air flowing through the vocal cords” (Ohala, 1997). A stop consonant occurs when there is supra-glottal closure that impedes, or by definition stops, the flow of air from the lungs through the mouth. When this occurs there is an associated intra-oral pressure rise. The volume of air released and the value of peak pressure are both dependent on the glottal aperture and also the amount of air stopped behind the articulators.

The presence or absence of voicing is a key differentiator of stop types. Kohler (1984, p. 152) notes that it is important to avoid confusion between phonetic and phonological ‘voicing’, and the terms voiced and voiceless, by reserving them exclusively for the presence or absence of glottal pulsing. In a similar vein, Ladefoged and Maddieson (1996) say that “... for some linguists, voicelessness invariably implies an open glottis, whereas for others it means an absence of vibration, whether produced by active laryngeal control or not”. It is important to bear this distinction between active and passive devoicing in mind when describing the phonatory differences that accompany their production.

Docherty (1992, p. 4) points out that there is a particular sequence of events necessary and a number of conditions that must first be met for the production of voicing. There must be adduction of the vocal folds and they must have the required tension. A trans-glottal pressure drop is normally achieved by a pulmonic-egressive airstream. The contraction of the lungs which lowers the pulmonic volume enables air to pass through the open glottis. In contrast a closed glottis, blocks the channel to the supra-glottal cavities.

It is also noted by Docherty (1992, p. 5) that vocal fold vibration cannot be instantaneously turned on or off by a speaker it is a feature that is gradient and gradual. Catford (1977, p. 107) is acknowledged in Docherty (1992) as “... one of the few investigators who explicitly recognise the gradual nature of

laryngeal activity, suggesting that it may be appropriate to think of laryngeal gestures as forming a ‘quasi-continuum’ ranging from complete voicelessness with abducted vocal folds through to a glottal stop with the vocal folds held tightly together, with voicing located somewhere in between”.

Fine-grained motor-control of voicing and other supra-laryngeal gestures is highly variable speaker to speaker. This makes it difficult to compare data from different speakers but there is evidence that there are certain sequences of events that must be in a particular order.

Voicelessness denotes a wide range of possible laryngeal configurations. Docherty (1992, p. 6) lists them as:

1. Complete glottal closure as observed in the production of a glottal stop;
2. a near-complete glottal closure as observed in the production of whisper...
3. an open glottis as the result of a full glottal abduction gesture.

It is generally accepted that the glottis is closed or nearly closed for voiced sounds but open for voiceless sounds (Sawashima & Hirose, 1983). In Fukienese, a dialect of Southern China, there are phonemically contrasting word initial voiceless stops. The language employs both voiceless aspirated stops and voiceless unaspirated stops within the phonology. Glottal width in a number of utterances was measured by Iwata, Sawashima, Hirose and Niimi (1979) cited in Sawashima and Hirose (1983). In aspirated stops the width of glottal aperture is large and the peak glottal width occurs at or very close to the time of release. This creates a large amount of airflow which delays the onset of voicing. In contrast the unaspirated stops show that, although the glottis is open, the glottal aperture is far less and the glottis is closed or nearly closed at the point of release. This is similar to Korean which has a three-way distinction in word initial oral stops. These have been labelled lenis, fortis and aspirated.

In English, fortis stops in word final as well as medial positions, can be pre-glottalised and in some cases weakly ejective. This suggests that they are articulated with leading or simultaneous glottal closure but not abducted (Jansen, 2004, p. 50). Furthermore Jansen (2004, p. 51) says, that it is possible to measure voice termination time as a phonetic cue to the contrast between lenis and fortis stops in English and Dutch, although notes that it is based on impressionistic data.

In the current study, the terms ‘voiced’ and ‘voiceless’ are strictly reserved for the presence or absence of glottal vibration. They are not used to denote phonological categories with the perceptual qualities of ‘voicing’. The phonological categories that are investigated are referred to as lenis and fortis which are defined in the section below (§ 2.1). Importantly, these terms are not used to predict the state of the glottis of an individual articulation. Any glottal state will be inferred using indirect instrumental measurement of pressure, flow and glottal activity.

2.4.1 Analyses of voicing patterns

As introduced above in § 2.1, an accepted definition of fortis stops is that they are articulated with greater glottal tension which may be related to greater respiratory effort. Laryngeal setting (adduction), along with changes in airflow has a central role in the control of voicing (Warren, 1976). In this respect, the larynx is not merely a passive source generator but closely co-ordinated with the aerodynamic system. The changes in the tension of the vocal folds along with other aerodynamic factors such as an adequate trans-glottal pressure differential (van den Berg, 1958), are crucial in initiating and maintaining voicing and also in the cessation of vocal fold vibration (Yoshioka, Löfqvist, Hirose, & Collier, 1986, pp 55–6). Descriptions of the differences in stop categories need to go beyond measurements of voice onset time and must include information about laryngeal setting in the transitions into and out of intervocalic conso-

nants.

Voicing analyses have been used to infer glottal tension previously such as the study by Hardcastle (1973) on Korean tense and lax stops. Voice analyses are common in the clinical setting with many investigations into pathological and non-pathological voicing that make use of measurements of phonation type (Abberton & Fourcin, 1997; Abberton, Howard, & Fourcin, 1989; Baken & Orlikoff, 2000; Baken, 1992; Gauster, Yunusova, & Zajac, 2010). Another area in which a large quantity of research into voicing has been undertaken are investigations into phonation in the singing voice which has led to many novel methods for directly and indirectly observing changes in glottal setting (Bouhuys, Mead, Proctor, & Stevens, 1968; Herbst & Ternström, 2006; Howard, Lindsey, & Allen, 1990; Howard, 1995; Mecke, Sundberg, Granqvist, & Echter-nach, 2012; Sundberg, Andersson, & Hultqvist, 1999). Many of these previous studies have relied solely on acoustic measures but there are also many that use electroglottography (EGG) or a combination of acoustics and EGG. Comprehensive voice analyses are also commonly used to investigate the phonetic differences found between phonation types within languages (DiCanio, 2009; Esposito, 2010, 2012; Garellek, Keating, Esposito, & Kreiman, 2013; Huffman, 1987).

2.4.2 Voicing and devoicing: active and passive

Voicing in consonants can be actively extinguished with an abduction gesture of the vocal folds and this has been shown experimentally. Alternatively passive expansion of the vocal tract allows for voicing to be prolonged after stop closure (Rothenberg, 1968; Westbury & Keating, 1986). This passive expansion occurs when intra-oral pressure increases causing an expansion of the soft tissue behind the stop closure within the oral cavity.

If vocal fold vibration is to continue during at least a portion of the closure interval, as required for a voiced stop consonant, the volume

of the vocal tract must expand so that the trans-glottal pressure is sufficient to maintain vibration (Stevens, 1999, p. 466).

Without an associated passive enlargement of the vocal tract a voiced stop would become devoiced after only 5–10 ms and a voicing longer termination time after stop closure is due to oral cavity expansion in order to maintain the trans-glottal pressure differential required for voicing (Ohala & Riordan, 1979).

Jansen (2004, p. 38) (citing Ohala 1983; Westbury & Keating 1986; Stevens 1998) highlights that utterance medial post vocalic plosives can be passively devoiced for up to 25–100 ms after closure (oral occlusion) and that this is dependent on sub-glottal pressure, relative tension of the surrounding tissue within the vocal tract, and the place of articulation. These observations are supported by vocal tract modelling and observations in natural language. A voiceless obstruent which follows a voiced segment will have 20 ms to 60 ms of passive voicing unless specific laryngeal adjustments are made to prevent it (Westbury 1983, Westbury & Keating 1986, Stevens 2000, and Jansen 2004, cited by DiCanio (2012, p. 268).

Place of articulation influences the amount of passive devoicing found in the stop closure; Westbury and Keating (1986) estimate that the duration of the voicing tail—i.e., voicing continued from a preceding sound—in velar stops particularly, may be as much as 30% shorter than those in the corresponding bilabials. This is due to the fact that the size of the cavity behind the constriction is smaller in velars than in bilabials. Articulations at the velar place of articulation have a vocal tract lined with tissue that is less able to expand in response to airflow through the glottis (Jansen, 2004, p. 38).

Anterior places of articulation have the potential to passively voice for longer into the stop closure than more posterior articulations such as velars. Cross-linguistically voiced stops are said to be more common at anterior places of articulation and less common at posterior places of articulation (Ohala & Riordan, 1979, p. 89), and in addition it has been noted that a preceding nasal

in a nasal + stop cluster can influence the amount of passive devoicing in the following stop (Westbury & Keating, 1986). Passive voicing is common cross-linguistically and Jansen (2004, p. 43) says that, “...there is considerable speech production evidence to support the idea that any prevoicing observed in lenis plosives in English and other aspirating languages reflects passive voicing rather than a (weakly) voiced phonetic target”.

Active devoicing occurs when there is an adjustment made that provides the required conditions making voicing impossible due to the required trans-glottal pressure differential not being met (van den Berg, 1958). If the pressure conditions are not optimal, voicing cannot be maintained. Active devoicing is less common cross-linguistically but fortis obstruents in Itunyoso Trique are shown to undergo an active devoicing gesture in order to actively extinguish voicing after closure and speakers achieve this by a glottal spreading—or abduction—gesture at the onset of the stop (DiCanio, 2012, p. 268).

Chapter 3

Nasals and coarticulation

Nasal consonants and sonorants in general are an important phonemic class amongst Australian languages. The examination of timing in nasal stops is an important area of research as it gives insight into general coarticulatory patterns in a language. This chapter looks at previous research in nasals and coarticulation in general.

The velum has been characterised as a sluggish articulator that does not open in a single muscular gesture (Bell-Berti, Krakow, & Ross, 1993; Bladon & Al-Bamerni, 1982). Ohala (1975) says that there is very little experimental evidence to prove that the velum moves any slower than the vocal folds or the lips and that it is probably less slow in its movements than the tongue body (Hudgins & Stetson, 1934 cited in Ohala, 1975). It was shown by Clumeck (1976) that the velum lowered earlier in American English and Brazilian Portuguese than in French, Chinese, Swedish and Hindi. As noted by Chafcouloff and Marchal (1999, p. 79), this is in opposition to observations by Ohala (1974) which supported results by Dixit and MacNeilage (1972). Dixit and MacNeilage (1972) showed that velic opening was similar in vowels that had both ‘distinctive’ and ‘non-distinctive nasalisation’. Dixit and MacNeilage (1972) also showed that a nasal can affect segments well in advance of the nasal segment. This has given rise to the claim that “in general a preceding nasal consonant is less influential

in affecting the nasalisation of the vowel than the following nasal” (Chafcouloff & Marchal, 1999, p. 79).

Flege (1988) explored anticipatory and carry-over nasalisation in a clinical setting and compared the speech of children and adults. He used a measure of “nasalance” introduced by Fletcher, Sooudi, and Frost (1974), which is a ratio of oral intensity and combined oral and nasal flow. The results of the study showed that adults and children nasalised vowels in a d_n context and also in an n_d context which Flege suggests is not an effect of language learning but is a natural speech process. Flege (1988, p. 534) says that “[t]he data are consistent with the belief that carry-over coarticulation depends on inertial properties of the speech production mechanism.”

In this study the term ‘nasal’ is used in preference to the synonymous term ‘nasal stop’ (Ladefoged & Maddieson, 1996). In nasals there is obstruction in the oral cavity at various places of articulation but due to the opening of the velic port there is also a continuous stream of air from the lungs that is released through the nose. Consequently it does not qualify as a stop by the above definitions. Nasals share many similarities to oral stops in that there is constriction in the oral cavity, and in sharing the same place of articulation as an oral stop.

“The oral cavity acts as a side branching resonator to the main nasal-pharyngeal cavity and this results in oral *antiformants* that absorb energy from the main nasal-pharyngeal tube. The presence of anti-formants is one of the reasons why the overall amplitude of nasals is low. (Another is that because the mouth cavity is sealed, the amount of acoustic energy leaving the vocal tract is much less than for vowels).” (Harrington, 2012).

3.1 Place of articulation cues in nasals

Nasals tend to mask place of articulation due to the presence of ‘antiformants’ or zeros in the frequency spectrum which obscure or confuse transitional spectral cues at the onset and offset of nasals. These phonetic cues are essential for identifying the place of articulation of a nasal.

It has been shown perceptually that the transitions into and out of nasals convey the majority of the place of articulation information (Miller & Nicely, 1955). The resonances—or nasal murmur—present during oral occlusion primarily serve to indicate the manner of articulation and have very little information regarding place (Malécot, 1956, p. 274). The dominant frequencies found within the nasal murmur have shown to be dependent on the place of articulation. Recasens (1983), in a study of Catalan nasal phonemes, found that transitions provide more robust place of articulation cues than the murmurs. Despite this, nasal murmur still provided a significant contribution to differentiating nasals, especially apicals from velars due to overall differences in the spectra. The transitional information was most important for the identification of palatal nasals [ɲ] and least salient for the identification of velar nasals [ŋ]. Kurowski and Blumstein (1984) provide experimental evidence that the nasal murmur is as important as transition cues for providing place of articulation identity, particularly in English.

French and many other languages do not constrain the timing of velar lowering in order to delay nasalisation. “English often is assumed to have a general rule of Anticipatory Vowel Nasalisation of the form $V \rightarrow \tilde{V} / _N$ ” (Cohn, 1990, p. 139). Although this is true for many languages there are a significant number of languages for which this rule does not hold.

If anticipatory nasalisation is indeed part of the phonology of English, we would expect to see a significant amount of nasalisation for most or all of the duration of the vowel preceding a nasal con-

sonant. This expectation follows from our observation of the nature of nasal vowels in French... If on the other hand nasalisation results typically for only a portion of the preceding vowel and is observed to occur in a gradient manner, it should be concluded that the nasalisation is a result of phonetic implementation rather than phonological rule (Cohn, 1990, p. 139).

The nasal murmur has a complex spectral composition that not only has strong formant information also has the presence of prominent anti-formants which is a defining characteristic of nasal articulations. For bilabial nasals the antiformant is found in a region between 1–1.5 kHz. This negative resonance is slightly lower for apical and palatal nasals (Harrington & Cassidy, 2000; Johnson, 2003, p. 152).

3.1.1 Spectral properties of nasals

Nasals have a characteristic formant and an antiformant configuration that varies according to place of articulation. Relatively few studies exist that show the differences in spectral characteristics between nasals other than comparisons of apicals /n/ and bilabials /m/. Even the velar, due to its restricted distribution in English, is not often described cross-linguistically. Recasens (1983) in a study of Catalan is an exception and the Catalan phoneme inventory contains palatal nasals [ɲ]. This provides some comparison to the palato-alveolar nasal phonemes found in Bininj Gun-wok (for a summary see Ladefoged & Maddieson, 1996, p. 117).

The closer an articulation is to the uvular region of the oral tract, the higher the first nasal resonance and the nasal zero, called the oral zero by Ladefoged and Maddieson (1996, p. 116). This may be due to a decrease in the size of the pharyngeal cavity due to the posterior positioning of the tongue. Otherwise it may be due to a narrowing of the velo-pharyngeal aperture as the velum has lowered. As noted by Ladefoged and Maddieson (1996), the size of the

nasal cavity itself does not change as it is a rigid structure and does not have inherent elasticity in the surrounding tissue unlike that of the supra-laryngeal oral cavity.

3.1.2 Aerodynamics in nasals

Nasalisation in French has been studied widely, with an emphasis on phonological contrasts regarding nasalised and non-nasalised vowels. The degree and directionality of the nasal anticipation have been repeatedly investigated using a variety of instrumental phonetic techniques. In standard French, Basset, Amelot, Vaissière, and Roubeau (2002) found that the temporal extent of anticipatory nasal airflow was greater in phonologically oral high vowels, and that high and low vowels were both heavily affected by carry-over nasalisation.

In a later study of French nasalisation, Delvaux, Demolin, Harmegnies, and Soquet (2008) set out to improve on the methodologies of previous research. They use concurrent oral and nasal airflow records for a large corpus of read speech utterances. Results show that there is very little anticipatory nasalisation in the non-nasalised vowels and that the amount is marginally greater for high vowels than low vowels.

Huffman (1989) has applied a windowing phonological model (Keating, 1990) (see § 3.2.1, below) to aerodynamic data in nasals from the languages Yoruba and Akan and looks at the disparity between the phonetics and phonology of nasals. Huffman examined phonological landmarks in the aerodynamic signal in order to map the dynamic phonetic signal onto an Articulatory Phonology style phonological framework (Browman & Goldstein, 1992). The coordination of acoustics and aerodynamics was central to the discussion.

A selection of other studies use aerodynamics in the analysis. Riehl (2008) has examined the phonetic properties of nasal obstruent sequences with some limited reference to aerodynamic data, looking at prestopping that is prevalent in languages in a number of Austronesian languages. Cohn and Riehl (2008)

have also built on this analysis looking at nasals and stops in clusters and what they term ‘unary sequences’ that are equivalent to prestopped or postploded nasals with some very limited aerodynamic data (Maddieson, 1988, 1989; Maddieson & Ladefoged, 1993; Riehl & Cohn, 2011).

3.1.3 Vowel height and nasalisation

There is a close relationship between nasal air flow and vowel height. Nasal airflow is substantially greater in high vowels when compared with low vowels in the same VN (vowel followed by a nasal) context (Al-Bamerni, 1983; Lubker & Moll, 1965; McDonald & Baker, 1951, cited by Hajek, 1997). This is due to increased tongue height allowing greater constriction in the oral cavity to be formed. This results in greater impedance to oral airflow and thus more air flowing through the nasal cavity for high vowels. This difference in the total airflow is found in the nasalised vowels of Hong Kong Chinese (Khioe, 2004).

It has been reported cross-linguistically that in “...oral contexts, high vowels are produced with higher velum and greater velopharyngeal closure force than low vowels” (Delvaux et al., 2008). Similar findings are found by Bell-Berti and colleagues which show that in nasal contexts the high vowels are generally realised with less velopharyngeal opening than the low vowels (Bell-Berti, 1976; Bell-Berti & Krakow, 1991).

Delvaux et al. (2008) show experimentally that in French there is greater anticipatory nasalisation in high vowels than in non-high vowels. “In VN items, nasal airflow onset is either synchronous with oral closure or anticipated through about 25% of the vowel duration whereas in NV items, nasal airflow remains above zero level through 80% or more of the vowel” (Delvaux et al., 2008).

There can be no investigation into connected speech without taking into account coarticulatory processes and this is true not only of nasals. In Chapter 6, the influence of stops on the surrounding vowels is quantified using formant transition information found in the acoustic signal. In Chapter 9 the coarticula-

tory patterns in nasals are investigated using aerodynamics. Before proceeding with the analysis, a selection of coarticulatory theories are discussed with reference to the experimental measures discussed in the methodology (Chapter 5).

3.2 Coarticulation and assimilation

In natural language no speech segment is uttered in isolation. The environment of surrounding segments exert a level of influence on a particular segment and this is known as coarticulation. The effects of coarticulation are largely inaudible and as a consequence measuring its effects acoustically can be challenging. After the advent of modern physiological and acoustic techniques in the study of speech the close examination of coarticulatory effects is now possible (Farnetani & Recasens, 2013, p. 316). As noted by Löfqvist (2012, p. 353), when movements associated with speech are recorded the resulting signals can be described as a series of opening and closing actions. These actions are not discrete and in connected speech they combine and blend to varying degrees to form utterances. The constraints on these coarticulatory events are thought to be the result of physical processes. Consequently coarticulation is governed by universal rules that generally hold cross-linguistically.

Fowler and Saltzman (1993, p. 173) define coarticulation as “... the fact that at any given point during an utterance, the influence of gestures associated with several adjacent or near adjacent segments can generally be observed in the acoustic or articulatory patterns of speech.”. This describes speech in terms of a co-production model in which each segment is influenced to specific degrees by the surrounding segments. The co-production model and the proposal for a phonology that is based primarily on articulatory landmarks is discussed further in the following subsection (§ 3.2.1).

3.2.1 Models of coarticulation

There have been a number of proposed models that attempt to describe and account for patterns of coarticulation. These are generally divided into two types of coarticulatory model: feature spreading models (Joos, 1948 and Henke, 1966, cited in Bell-Berti & Krakow, 1991) and co-production models (Bell-Berti & Krakow, 1991).

Emerging from feature-based phonology (Chomsky & Halle, 1968), a number of explanations for coarticulatory patterns have been proposed. The window model (Keating, 1987, 1990), has been applied to nasal coarticulation by Cohn (1990) who examined three languages, Sundanese, French and English. In this model, cross-linguistic differences in coarticulation may be categorised as either phonetic or phonological and it is only through analysis of a particular language that these patterns can be categorised as one or the other (Farnetani & Recasens, 1999, p. 47). The time-locked or ‘temporal overlap’ model, which was developed by Bell-Berti and Harris (1981), builds on Öhman (1966a), and is closely aligned with coproduction models (Bell-Berti & Krakow, 1991).

A model with the gesture as the central aspect of the theory, developed out of these coproduction models. Articulatory Phonology (Browman & Goldstein, 1990a, 1992, 1990b, 1990c) and the associated Task-Dynamic models of speech (Byrd & Saltzman, 2003; Saltzman & Byrd, 2000; Saltzman & Munhall, 1989; Saltzman, Rubin, Goldstein, & Browman, 1987) propose a phonological theory based on inter-gestural timing. Articulatory Phonology is the formal phonological theory whereas Task Dynamics is a quantitative framework that implements the phonological units (Byrd & Saltzman, 2003). In both Articulatory Phonology and Task Dynamics, speech is described in terms of articulatory landmarks, kinematics and phasing of the articulators (Harrington, 2010, p. 115). In an Articulatory Phonology framework the gesture is both a unit of production and a unit of information (Byrd & Saltzman, 2003). A gesture is invariant and the surface realisation of a phoneme is a result on co-production with surrounding

segments (Kühnert & Nolan, 1999, p. 23).

Articulatory Phonology focuses on inter-gestural organisation in a way that makes it ideally suited for accounts of coarticulatory effects due to the interaction of different speech sub-systems.

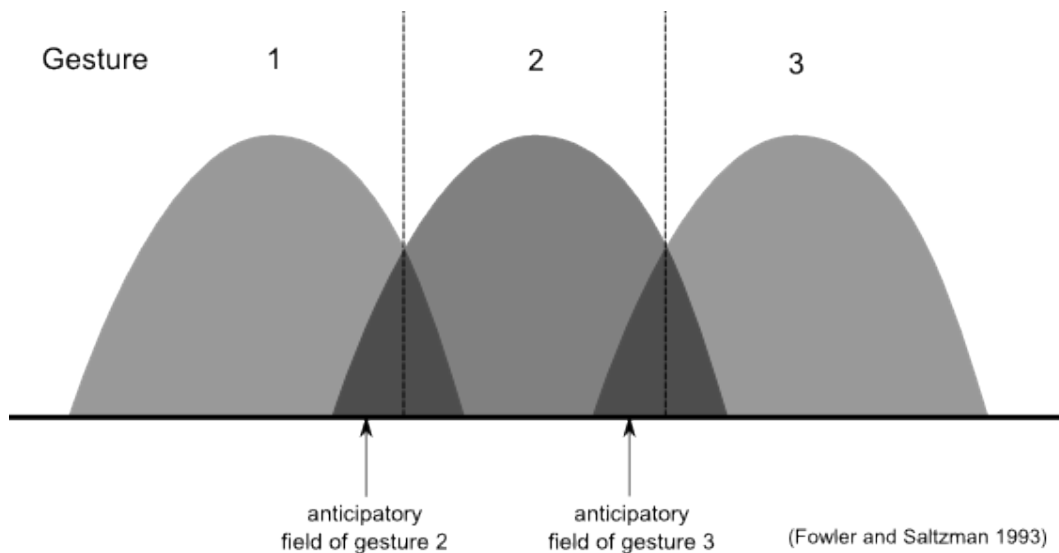


FIGURE 3.1: A schematic representation of the overlapping coarticulatory effects of three gestures, after Fowler and Saltzman (1993, p. 184).

In the simplest form, gestures affect the articulation of adjacent gestures to varying degrees as shown in the schematic diagram of coarticulatory effects (Figure 3.1 from Fowler and Saltzman, 1993). This figure shows three separate gestures that have influence on the gestures around them. The anticipatory field of the gesture, as Fowler and Saltzman define it, is the influence of a particular segment on the preceding segment. However coarticulation is bidirectional with some carry-over influence exerted on the following segment. A single gesture may not exactly coincide with the acoustic output of a segment and connected speech is the result of many blended gestures that are the co-ordination of a number of different articulators in terms of both timing and magnitude. This disconnect between the acoustic output and the underlying gestures has left Articulatory Phonology open to criticism as it does not directly account for the perceptual aspects of speech (Kühnert & Nolan, 1999).

Coarticulation occurs in any adjacent segments to some extent, not only occurring within words but also potentially across boundaries at all prosodic levels. Byrd and Saltzman (2003) have proposed a type of prosodic gesture that accounts for phrase final lengthening. This is where phrase initial and final gestures are subject to lengthening (Beckman, Edwards, & Fletcher, 1992; Edwards, Beckman, & Fletcher, 1991). These prosodic gestures (or π -gestures) are superimposed on the other gestures and can be added as additional tier in the gestural score. The gestural score is central to Articulatory Phonology (see Browman & Goldstein, 1992, p. 158 for an introduction to gestural scores).

3.2.2 Coarticulation resistance

Certain gestures more readily coarticulate with surrounding segments. Theories of why this is the case have also followed on from a feature-based phonology. One such theory of coarticulation, fitting within a feature spreading framework, is ‘coarticulatory resistance’ (Farnetani & Recasens, 1999, p. 44). Bladon and Al-Bamerni (1976) first used the term ‘coarticulatory resistance’ to describe the different behaviour of particular phonemes in terms of the influence of neighbouring segments (Modarresi, Sussman, Lindblom, & Burlingame, 2004, p. 3). The idea that certain phonemes are more or less likely to coarticulate with surrounding phonemes has been a significant influence on Recasens’s DAC (Degree of Articulatory Constraint) model of coarticulation (Iskarous et al., 2013; Recasens, 1984, 1985, 2004; Recasens & Espinosa, 2009; Recasens & Pallarès, 2001; Recasens, Pallares, & Fontdevila, 1997). Recasens and Espinosa (2009) say that “[c]oarticulatory resistance for a given consonant or vowel is a measure of its degree of articulatory variability as a function of phonetic context.”

Australian languages have shown little or no anticipatory place of articulation assimilation unlike many other languages (Fletcher, Butcher, Loakes, & Stoakes, 2011). Manner of articulation assimilation has also been shown to be blocked in medial position particularly in the case of nasals (Butcher, 1999).

This will be discussed further below in relation to the current study as well as Butcher's theories on consonant articulation across Australian languages in § 4.3 (Butcher, 2006a).

3.2.3 Locus equations

Locus equations have been used in a number of previous studies to measure vowel to consonant coarticulation. The Locus Equation (LE) can be defined as "...linear regressions of the frequency of F2 transition sampled at its onset (F2 onset) on the frequency of F2 sampled in the middle of the following vowel (F2 vowel)" (Modarresi et al., 2004). This measurement predominantly used to examine place of articulation and uses transition information sampled at two points in a vowel followed by a consonant (VC), or consonant followed by a vowel (CV) (see § 5.6.9 for a definition of the metric used in this study). Sussman and colleagues (1991; 1991) investigate the 'locus' concept that resulted from research at Haskins on the phonetic cues to place of articulation for consonants (e.g. Delattre, Berman, & Cooper, 1962; Delattre, Liberman, & Cooper, 1955). The aim was to find a relationship between second formant frequencies (F_2) at the onset and midpoint of vowels and to see if this locus was consistent for each place of articulation. Prior to this the locus measurement had been investigated in great depth by Krull (1987, 1989) who was influenced by early work by Lindblom (cited in Lindblom, Agwuele, Sussman, & Cortes, 2007).

Consonant F_2 trajectories and loci have been found to be vowel dependent by Öhman (1966a, 1966b) in investigations of vowel to vowel coarticulation for a production and perceptual perspective.

A number of studies of Locus equations have supported a relationship between the slope of the regression line and the degree of coarticulation with the slope of the regression increasing with coarticulation degree (Iskarous, Fowler, & Whalen, 2010; Modarresi, Sussman, Lindblom, & Burlingame, 2005; Sussman, Dalston, & S., 1998; Sussman, Fruchter, Hilbert, & Sirosh, 1998; Sussman,

Hoemeke, & Ahmed, 1993; Tabain & Butcher, 1999a). There has been some criticism of the locus equation measurement, specifically by Löfqvist (1999) who presents evidence to show that a link between the slope of a locus equation and the degree of coarticulation (or articulatory overlap) should be questioned. He bases these concerns on an articulatory examination of English speakers which shows: “[t]he hypothesis is not supported because of the finding that labial stops in different vowel contexts have similar slopes but differ in degree of coarticulation, and also by the finding that alveolar and velar stops differ in slope but show the same degree of coarticulation” (Löfqvist, 1999, p. 2029). Fowler (1994) has also been critical of the ability of consonant loci alone to provide sufficient place information to listeners. These results are reiterated by Brancazio and Fowler (1998) who found that locus equations were no better than an exemplar model at predicting place of articulation as there was a high degree of variance in listener responses when locus dependent cues were controlled.

Locus equations have been used previously to good effect in investigations of place of articulation assimilation and coarticulatory effects in VC and CV sequences amongst Australian languages (Graetzer, 2012; Tabain, 2000, 2002; Tabain & Butcher, 1999b). In addition, Tabain and Butcher (1999b) show that in two Australian languages, Yanyuwa and Yindjibarndi, there are high slope values for bilabials and velars and lower slope values for the coronal consonants. The locus equation (LE) data could not separate coronal consonants, particularly those that had four coronal places of articulation. This is a similar result to that found by Krull (1995) in a cross-linguistic study. Lindblom et al. (2007, p. 3812) caution against using LE slopes as numerical markers of degree of coarticulation however and says that both emphatic stress, a close corollary of fortition, and tempo need to be taken into account when interpreting the results of locus equations.

Graetzer (2012) found that consonant place of articulation has a very strong

effect on the surrounding vowels in vowel-to-vowel coarticulation in four Australian languages, Arrernte, Warlpiri, Burarra, and Gupapuyngu. This study adds to the previous studies of vowel-to-consonant coarticulatory patterns in Australian languages by examining any differences between the coarticulatory effects of lenis and fortis stops in Bininj Gun-wok. This is to examine whether inherently strong articulations—whether a function of prosodic position or due to a phonological opposition—are more or less likely to coarticulate with the surrounding segments.

3.2.4 Nasal assimilation and coarticulation

Place of articulation is not the only assimilation that can affect surrounding consonants. Manner of articulation can also assimilate in either a progressive or regressive direction. Nasalisation is when the nasal manner of articulation spreads to surrounding segments. There have been claims that the direction of the nasal assimilation is largely universally determined (Kawasaki, 1986).

Studies of the coarticulatory effects of nasalisation are usually divided into two types, an examination of the contextual effects and an examination of the directionality (Bell-Berti, 1993, p. 71). The term nasal coarticulation is often used synonymously when there is a spreading of the nasal feature onto the adjacent segments (Chafcouloff & Marchal, 1999) (see ‘feature-spreading’ models above in § 3.2.1).

Most researchers are in agreement that carry-over nasal coarticulation is due to inherent biomechanical (or mechano-inertial) properties of the velopharyngeal system (Chafcouloff & Marchal, 1999, p. 75). This has been observed in English speaking adults and children (Flege, 1988). Farnetani and Kori (1986), found that aerodynamically, in Italian “...the nasality from the consonant /n/ extended more into the following vowel than into the preceding one” (Chafcouloff & Marchal, 1999, p. 74). This aspect of carry-over coarticulation has also been observed by Delvaux et al. (2008) for French.

Nasal articulation in Australian languages is introduced in § 4.2 and the quantitative analysis of Bininj Gun-wok is presented and discussed in Chapter 9.

Chapter 4

Australian languages and medial consonant articulation

In Australian languages it is consonants, particularly those in a medial position, that carry much of the functional load in terms of phonological differences. There are numerous places of articulation that need to be kept distinct. On one hand, the vast majority of the languages lack phonemic fricatives and consequently the number or manner of articulation distinctions available at each place of articulation is greatly reduced. On the other, hand sonorant consonants such as nasals and approximants—both lateral and rhotic—are well represented in the phonology of these languages (Butcher, 2006a). The phonetics of Bininj Gun-wok is discussed at the end of this chapter.

This chapter examines previous phonetic studies of consonants across the languages of Australia; in particular within the small group of Australian languages that have an attested length contrast word medially. Voicing in Australian languages is highlighted, particularly the interaction with strengthening of consonants in the medial position. This is thought to ensure the cues for place of articulation are kept distinct. It is still unclear the factors which govern variation in observed voicing patterns across Australian languages. A thorough description of these patterns is most important in languages, such

as Bininj Gun-wok which have a phonological distinction between stop types where voicing does not seem to play a role. Although there is voicing variation, in many cases the phonetic realisation is highly consistent when an individual speakers are observed.

4.1 The stop contrast: double stop series in Australian languages

A single stop series is a rarity cross-linguistically, with only about 16% of languages without a phonological voicing contrast in stop consonants (Maddieson & Disner, 1984, p. 26–7). By comparison, the majority of Australian languages only have a single series of obstruent consonants with no phonological voicing or aspiration contrast. There are, however, a significant percentage of Australian languages that do have two stop series and it is estimated that about 30% of languages—mainly found within the Non-Pama-Nyungan group—have this phonological contrast (Butcher, 2004). The phonetic realisation of the stops is highly variable from language to language however, with some favouring fully devoiced stops and others lenited, voiced stops that are better described phonetically as an approximant than as a plosive. On the surface these allophonic realisations seem to be in free variation although there are some restrictions that are largely speaker specific.

The phonetic nature of stop contrasts in those Australian languages that have two stop series has been a major source of discussion within the linguistic literature. This is discussed further below. The phonetic correlates that correspond to the phonological categories are not clearly defined and the appropriateness of the labels, particularly lenis and fortis, needs further quantitative scrutiny (see § 2.1).

As discussed above, homorganic clusters of stops are common in Australian languages and these are often analysed as geminates in certain circumstances.

Detailed descriptions of grammatical gemination processes can be found for a selection of the Yolngu Matha group of languages, as well as Ngalakgan (Baker, 2008; Merlan, 1983), for example. These descriptions are largely phonological analyses referencing the morpho-syntax to support a structural argument. The central question common to these descriptions is whether word medial long stops are formed by gemination or whether they constitute a single segment (as discussed in § 2.2 on gemination). In Ngalakgan—a Gunwinyguan language closely related to Bininj Gun-wok—Baker (2008, pp 38–40) argues that the geminate analysis is the only possible analysis based upon distribution within the language. As discussed above in § 2.1 and § 2.2, there remains debate cross-linguistically as to whether there is any phonetic differences between geminates and long stops. In each of these descriptions, including those discussed further in the next section (§ 4.1.1), duration is cited as the major difference between the categories (Evans, 2003, p. 82).

Duration is the most readily measurable difference between stop types in a language. Yet this is not the sole cue to a contrast and many studies have shown that amongst many languages there is a regular difference in the voicing profile. However due to limitations in acoustic techniques voicing is difficult to measure using acoustic analysis alone. In the current study, multi-channelled aerodynamic and articulatory recordings are used as they provide additional information that can show, not only differences in duration but differences in articulatory strength and the inter-gestural coordination of the articulators. These timing event are important for the interpretation of voicing differences and the phonological consequences of these differences.

Physiologically, voicing is difficult to maintain in stops with a long closure duration. Vocal fold vibration is only possible while the trans-glottal pressure differential is sufficiently maintained (van den Berg, 1958). Voicing can be prolonged by increasing the total volume of the vocal tract, for example, by lowering the larynx along with expanding the soft tissue surrounding the vocal

tract in the cheeks or the pharynx (Ohala & Riordan, 1979). This cavity expansion serves to maintain the required pressure differential needed for voicing (see § 2.4.2).

Within Australian languages, Dixon (1980, p. 216) reports a contrast found between two categories of medial stop in some of the languages of Arnhem Land. This contrast puzzled early documenters of Yolŋu Matha (Yolngu Matha) who initially did not record the difference until Lowe (1963) described them as contrasting long and short consonants. For some time, the exact phonetic nature of the contrast was not investigated and it was analysed as a difference in quantity rather than quality. Lowe (1963) notes that in the Yolŋu dialect Gupapuyngu there is a length distinction in the medial consonants for some words but that this contrast was associated with voicing. In further descriptions of Yolŋu Matha, the long consonant is said to exhibit a delayed release when compared with the short consonant (Dixon, 1980). A similar phenomenon has also been described in Rembarrnga and Burarra (Dixon, 1980). Other descriptions of the various varieties of Yolŋu Matha include research by Schebeck (1968, 2001), Wood (1977, 1978), Walker (1984) and Wilkinson (1991).

As discussed above in § 2.2, McKay (1980) found a number of differences between two stop types when examining word medial stops and clusters in Rembarrnga. He argues that the medial stops are best described as single vs. geminate rather than lenis and fortis or voiced and voiceless (Ladefoged & Maddieson, 1996, p. 98). In a description of lenis and fortis consonants Ladefoged and Maddieson (1996, p. 98) cite McKay (1980, p. 346) who comments that using spectrographic analysis these data show “...geminate stops to be characterized by a more abrupt closure...and by a more prominent burst of noise at the point of release, with greater interval before voice onset after the release...than the corresponding single stops. These characteristics of the geminate stop may be considered indicators of fortis or tense articulation”. Burst amplitude differences in Bininj Gun-wok are investigated below in § 6.7.1.

In a study into the phonetic correlates of lenis and fortis, Jaeger (1983) measured aspects of the two stop series in Jawoyn (also referred to in the literature as Jawoñ or Djauan, a language closely related to Bininj Gun-wok). These data were compared to the measurements of fortis/lenis stops in an unrelated Mesoamerican language, Zapotec (Jaeger, 1983). This limited instrumental analysis used data gathered by Francesca Merlan in the course of compiling a Jawoyn dictionary and consulting on a land claim (Merlan & Rumsey, 1982). Jaeger (1983) states that length is the primary phonetic correlate of the lenis/fortis contrast in Jawoyn (see duration measurements and further discussion below in § 4.1.1). A further phonetic parameter that potentially cues a difference however, is glottal width which was inferred by Jaeger by observations of a dissimilarity in spectral intensity characteristics at the burst between the two stop types. This was similar to results noted by McKay (1980) in Rembarrnga. Both of these studies exclusively use acoustic recordings as their basis and as Ladefoged and Maddieson (1996, p. 98) note, neither Jaeger (1983) nor McKay (1980) provide aerodynamic evidence, making it difficult to determine whether there are any differences in respiratory effort associated with each stop category in addition to duration.

Butcher (1992, 2004) re-examines Jaeger's (1983) claim using aerodynamic results and shows that there is a difference between the stops series stops in some Australian languages including Bininj Gun-wok relating to differences in the timing of the peak intra-oral pressure. There are a number of possible ways in which an intra-oral pressure opposition can be realised. Firstly, there may be a particular target pressure for each contrasting stop and this pressure is maintained by either varying pulmonic pressure or secondly, by varying glottal area. Butcher argues that glottal aperture rather than respiratory effort is the main physiological parameter underlying the pressure variation in Australian languages "...and that each member of the opposition has a specific target pressure rather than the lenis peak pressure being truncated by the early release of

the articulatory closure” (Butcher, 2004, p. 547). It is also possible that glottal area and pulmonic pressure are equivalent in each of the contrasting phonemes and the differences in intra-oral pressure are due to differences in the closure duration (articulatory stricture). The fortis stop has longer to build up pressure than the lenis stop. However the pressure rises at twice the rate in fortis stops as it does in lenis stops regardless of stress position (Butcher, 2004).

Merlan’s (1983) work on Ngalakan describes the two stop series found in the language phonologically as fortis and lenis. Baker (1999) disagrees with Merlan’s interpretation and argues that they are better analysed phonologically as geminate vs. singleton. Baker characterises the long stop in Ngalakan as a geminate and argues that all long stops found in the language are clusters. Baker also argues that there is a single stop series and that to account for the phonetically long stops the single stops are geminated (doubled). This accounts for some interesting phonological facts about the language. Some previous phonological labels that have been applied to the opposition in question are: a voicing contrast; a fortis/lenis contrast; a geminate/singleton contrast; a long/short contrast (Baker, 1999, p. 106).

The glottal stop is phonemically contrastive in many Non-Pama-Nyungan languages and has full phoneme status in Bininj Gun-wok and it has distributional similarities to the fortis stops. (see § 1.3). These distributional anomalies regarding the of syllable placement of glottal stops is also found in Yolngu Matha. (Schebeck, n.d., 1968, 2001; Walker, 1984; Wood, 1977, 1978) and discussed by Carroll in reference to Kunwinjku (Carroll, 1976, p. 13):

“Some speakers have an unusual feature in their occasional aspiration of word final stops, particularly velar stops. This involves a slightly longer than normal closure phase, followed by a glottal stop with an accompanying nasal release of air. It seems to be limited to some people from the Gumaderr River area (50 miles east of Oenpelli) and may be a dialectal or idiolectal feature. The occurrence of

oral stops with a delayed, glottalised release of air through the nasal passage has also been reported in languages from north-eastern Arnhem Land "(Schebeck n.d.).¹

The nasal release feature described above by Carroll and Schebeck is found extensively in the current corpus. A possible reason for the release through the nose after a long stop closure is that there is tight closure in the oral cavity, and possibly at the glottis, and in addition the velopharyngeal port is lowered to equalise the pressure within the system thus allowing the glottis to open. Another possibility is that the glottis is open and there is tight closure in the oral cavity. The glottal stop is more restricted than any other segment (see § 4.4.3). The glottal stop can only follow sonorants and can only appear as the final element in a syllable coda (Baker, 2008). This is also true of long stops, but with one caveat—they cannot follow nasals. Baker (2008) goes on to say that sonorants are post-laryngealised in Ngalakgan which may be evidence of a vestigial glottal gesture after the nasal.

The lenis stop can be fully voiced, partially voiced or voiceless whereas the fortis stop is invariably voiceless which gives an indication of the variation found within Bininj Gun-wok. This may be only due to differences in duration between them however and as the duration increases the likelihood of prolonged voicing decreases. This hypothesis will be investigated quantitatively below. Related to the duration is the observation that there is a distributional parallel between long stops and heterorganic stop clusters (as Evans, (2003) too has observed). This gives some traction to a geminate interpretation of fortis stops. Baker (2008) regards geminates as boundary markers that delineate morpheme and word boundaries and he groups them functionally with the glottal stop. He argues that a boundary marker aids the parsing and perception

¹This is the geographical location (along the Goomadeer River [kumɛdːɛr]) that the speakers in the current study belong and I believe this is the same dialect or sub-dialect group referred to by Carroll (1976) and Schebeck (n.d.).

of complex words which is essential in a polysynthetic language such as Bininj Gun-wok. This important idea is central to the motivation behind the first two experiments in this study and one that may reveal an analysis alternate to the geminate one.

4.1.1 Experimental research: the stop contrast in Australian languages

Duration of articulatory stricture has shown to be the most consistent phonetic cue to the difference between stop series in Australian languages. Consequently, there are many studies that report differences between stop types at the same place of articulation (see below). Data from seven Burrarran-Gunwinnguan languages (Butcher, 2006b), shows that duration is the primary difference between stop series in all of the languages. The results are summarised in Table 4.1. The duration measurements for six languages are reported; data for three languages—Burrarra, Gurr-goni and Kunbarlang gathered by Butcher (1989); the additional data coming from other researchers, noted in parentheses. The seventh language, Jarwyon (from recordings by Merlan) is shown separately in Table 4.4.

In each of the languages—shown in Table 4.1 above—the absolute duration of the medial consonants is variable, dependent on both the stop type but also the place of articulation. Overall the ratios are between 1:2.3–1:3.7 for lenis:fortis stops. Duration results for some languages unrelated to Bininj Gun-wok are shown in Table 4.2, which reports data collated and summarised by Butcher (2006b). The durations serve as a comparison with the languages in Table 4.1 above. All values are shown in milliseconds (ms) with the overall ratio in the final column. Each of these languages have a slightly lower ratio of lenis to fortis stop durations, but the fortis stop is still approximately double the duration of the lenis stop.

Many other Australian languages have stops with a relatively long duration

TABLE 4.1: Average durations (in ms) of fortis and lenis stops in six Gunwinnguan languages related to Biniŋ Gun-wok (summarised in Butcher (2006b)).

		p/b	t/d	t̪/d̪	c/ɟ	k/g	OVERALL	RATIO
Burarra (Butcher)	FORTIS	205		193	182	180	190	1:3.4
	LENIS	62	44	40	76	59	56	
Gurr-goni (Butcher)	FORTIS	178		160	172	153	166	1:2.3
	LENIS	90		30	84	86	73	
Nakkara (Eather, 1990)	FORTIS	209	186	189	180	137	174	1:3.6
	LENIS	83	23	31	63	46	49	
Kunbarlang (Butcher)	FORTIS	137	195	238	196	147	183	1:2.8
	LENIS	77	45	38	92	78	66	
Rembarrnga (McKay, 1980)	FORTIS	131	193	125	230	127	170	1:3.7
	LENIS	62	35	21	66	60	46	
Warray (Harvey, p.c.)	FORTIS	155	144	134	154	155	148	1:2.5
	LENIS	61	58	55	65	60	60	

TABLE 4.2: Average durations (in ms) of fortis and lenis stops in three languages (from Harvey p.c. reported in Butcher, 2006b).

		p/b	t̪/d̪	t/d	t̪/d̪	c/ɟ	k/g	OVERALL	RATIO
Larrikiya	FORTIS	131	105		114	130	143	125	1:2.2
	LENIS	70	49	48		66	53	57	
Limilngan	FORTIS	172	117			114	131	134	1:2.0
	LENIS	83	68	55		63	65	67	
Wagiman	FORTIS	142	142	119		165	152	144	1:1.8
	LENIS	89	77	71		86	75	80	

found in the medial position. These include the languages of the Daly River such as Murrinh-Patha (Butcher, forthcoming) and also the Yolngu group of languages (Yolŋu Matha)—although the contrast is marginal at the apical place of articulation (see above in § 4.1). Medial stops are often long and voiceless in many Australian languages (for example Warlpiri and Arrernte) but they are not thought of as contrastive and may be more related to prosodic position. These languages will not be discussed further here, although it should be noted

that each of these languages is highly structurally different to Bininj Gun-wok with regard to both morphology and syntax.

Baker (2008) reports that the average duration for medial stops in Ngalakgan has a similar distribution (summarised in Table 4.3). These values are consistent with those reported by Butcher based on previous measurements by Merlan (1983). Fortis stops in Ngalakgan are between 150 ms to 250 ms in slow speech (Merlan, 1983, p. 2) but as Butcher (2006b, p. 13) points out there are no comparable figures for lenis stops. In Ngalakgan the long stops are phonologically classified as geminates.

TABLE 4.3: *Average durations of geminates (fortis) and singletons (lenis) in Ngalakgan (measured in ms) with number of tokens in parentheses (Baker, 2008).*

	LABIAL	ALVEOLAR	RETROFLEX	LAMINAL	DORSAL
FORTIS (Geminate)	(9) = 194	(5) = 139	(2) = 226	(2) = 228	(35) = 211
LENIS (Singleton)	(7) = 71		(23) = 48	(4) = 64	(6) = 63

According to Baker (2008), Ngalakgan long or geminate stops have more in common phonetically with geminates found in languages such as Finnish, Italian and Estonian than with stops described as ‘fortis’ found in English or German. He does not see the term fortis as productive in view of the phonological and morphological analysis of Ngalakgan (see discussion regarding gemination above in § 2.2).

Duration measurements made by Jaeger (1983, which are reproduced in Evans & Merlan, 2004, p. 203) are shown in Table 4.4. In addition, Jaeger measures the durations in clusters of sonorant and stops. Jaeger (1983), regards closure duration as the most important difference in Jawoyn (Jarwoñ) but additionally points to differences in glottal width and muscular tension as being also involved. Jaeger says that this does not necessarily correlate with a difference in strength. Jaeger (1983) infers both glottal width and the glottal tension indirectly using the acoustic signals. Jaeger (1983, p. 183) also

reports that stops are longest when they occur in word final position. In Bininj Gun-wok, fortis stops can *only* occur directly after vowels and non-nasal sonants (voiced consonant phonemes). Consequently clusters that containing long stops are relatively restricted and relatively rare.

TABLE 4.4: *Jarwon lenis (short) and fortis (long) stop durations (in ms) separated by place of articulation (from Jaeger 1983 p.183).*

	BILABIAL	VELAR	PALATAL	ALVEOLAR	RETROFLEX
FORTIS	138	153	109	139	187
LENIS	58	60	36	40	60

In Table 4.4 (Jaeger, 1983, p. 183), word final stops are grouped as fortis stops whereas word initial stops are grouped as lenis stops. The fortis stops were also measured after sonorants (nasals and laterals). Evans and Merlan (2004) reanalyse Jawoyn data, collected by Merlan and reported by Jaeger (1983). These data form the basis of a durational analysis.

4.1.2 The stop controversy

Evans and Merlan (2004, p. 187) highlight that most discussion concerning stop contrasts in Australian languages centres around phonological status rather than through analysis of the phonetics. Beyond the studies by Butcher (detailed above), there have been very few detailed phonetic studies of the stop contrast and very few concerning articulatory phonetics in Australian languages generally, presumably due to the difficulty in gathering primary data (Butcher, forthcoming; Jernudd, 1974; Proffit, McGlone, & Barrett, 1973). This section examines the controversy surrounding the appropriate labelling of Australian languages with two stop series.

The phonological categorisation of the two stops series has been a point of debate and this is surveyed at length by Evans and Merlan (2004). The cross-linguistic research below is also surveyed and expanded on by Butcher (forth-

coming) In Bininj Gun-wok and related languages a segmental analysis—two series of fortis versus lenis—or a geminate analysis have been posited (Butcher, forthcoming). A third possibility which is to treat the glottal stop as a prosodic feature of the syllable, and the fortis stops as allophones of a single underlying series following an underlying glottal stop is sometimes known as the ‘prosodic solution’ (Butcher, forthcoming; Schebeck, n.d., 1968). This is elaborated on by Baker (1999, 2008), who says that patterns of vowel allophony, when taken together with the syllable phonotactics of Ngalakgan, show that phonetically, long stops, either intra-morphemic or inter-morphemic, behave in a similar way to obstruent clusters and also to glottal stops.

Geminates commonly occur at stem boundaries in complex words in Ngalakgan and other Northern Languages. Glottal stops appear in all of the same environments, suggesting that the two—glottal stop, and geminate—perform a similar function (Baker, 2008, p. 241).

and also:

If geminates are heterosyllabic strings, then it is possible to make a simple generalisation: the initial part of the geminate, and glottal stops, both close the preceding stem-final syllable...That is, geminates, [spread glottis] clusters, and glottal stop all signal ‘word’ boundaries, where ‘word’ corresponds at least to Prosodic Word, and also to other prominent prosodic positions. (Baker, 1999, pp 141, 145)

Prior work by Baker (1999, 2008) these competing analyses of the stop series in Australian languages have been discussed at length. The majority of the research work concerns the Yolŋu Matha varieties. Many Yolŋu researchers favour a two stop phonological analysis, which they label fortis versus lenis and this is a major motivation for the labelling used in the current study.

It is the ‘segmental’ solution that assigns the lenis and fortis labels and this is the analysis that has been adopted for many descriptions of Yolŋu Matha phonologies. This segmental analysis is the basis for phonologies of, Gupapuyŋu (Lowe, 1963; Schebeck, 1968, 2001); Djambarrpuyŋu (Heath, 1980b) and Ritharngu (Heath, 1980a), Djinang and Djinba (Waters, 1984) Gälpu (Wood, 1978), Djapu (Morphy, 1983) and Rirratjingu (Schebeck, 1968).

As previously discussed above, Wood (1977) originally favoured the geminate solution for Gälpu, which he subsequently rejected (Wood, 1978), whereas Schebeck (n.d., 2001) later argued that the geminate analysis worked better for Gupapuyŋu and Rirratjingu. After this, Walker (1984), argued in favour of the prosodic solution for eastern Yolŋu languages which uses the distribution of the glottal stops as evidence of a prosodically motivated reason for the contrast.

A stop contrast is also found amongst the Daly languages. Some initial descriptions analysed this contrast phonologically as singleton and geminate, for example, Marranj (Maranungku) by Tryon (1970). Butcher (forthcoming) says that this geminate/singleton analysis was later generalised to all members of the Daly family (Tryon, 1974). In later analyses the stop contrast was reanalysed as voiced and voiceless (Hoddinott & Kofod, 1988; Reid, 1982). Butcher notes that in Marrithiyel, another Daly language Green (1989, p. 20) divides the obstruents into three groups according to the features long, short and fricatable. Interestingly, the Daly languages, are said to be some of the few Australian languages that contain phonological fricatives (see § 4.1.3). In Murrinh-patha, Walsh (1976) and Street and Mollinjin (1981, p. 184) also refer to the contrasting series as voiced and voiceless making this language unusual in that there are two stop series contrasts for voicing.

What is clear from these competing analyses is that there are no agreed upon phonological interpretation for the two stop series in Australian languages. It is possible that a single solution will not be sufficient to describe the contrast for all Australian languages. The surface realisations observed in these languages

may be more to do with morphological structure than articulatory differences. The phonetic realisation each of the medial stops in Bininj Gun-wok is examined below. Where the language fits typologically, however, must be the subject of future research.

4.1.3 Fricatives in Australian languages

Bininj Gun-wok along with the majority of Australian languages do not have contrastive fricatives in their phoneme inventories. There are, however, approximately 15% of Australian languages that are analysed with phonemic fricatives (Butcher, forthcoming) (see Table 4.5). The languages of the Western Torres Strait (e.g. Kalaw Lagaw Ya) have true fricatives in their phonology although they are unusual in an Australian context and there is some evidence to group them phonologically with Papuan languages (Butcher, forthcoming). The five Daly languages listed in Table 4.5 Ngan'gityemerri, Marrithiyel, Marrany, Marringarr and Marramaninjsji have contrasting examples of true phonological fricatives according to Butcher (forthcoming). This small set of languages, makes up only 2% of Australian languages. In the Daly languages, as well as Arrernte, Tiwi, Mawng and Iwaidja, the fricatives at the bilabial or velar places of articulation are almost always glides—phonetically approximant with some frication in their release. The two coronal places of articulation, however (retroflex and alveo-palatal) are true fricatives according to Butcher (forthcoming). The fricatives are almost all restricted to medial (M) position with the Daly languages showing them word initially (I). In Bininj Gun-wok many word medial lenis stops can be realised as fricatives or more usually as approximants. This allophonic variation is most prevalent in bilabials and velars. The apicals, however, are very rarely approximated. This weakening of the closure may be better termed lenition and due to lack of oral closure in an obstruent. Common phonetic realisations of Bininj Gun-wok medial consonants, based on previous observations, are discussed in § 4.4.

TABLE 4.5: Australian languages with fricatives, From Butcher (forthcoming), information combined from Sutton (1976), Busby (1980), Dixon (2002)
^a ^b.

LANGUAGE	BILABIAL	VELAR	DENTAL	RETROFLEX	APICAL	ALVEO-PALATAL	DISTRIBUTION
Western Torres Strait					s/z		I M F
Arrernte		ɰ					M
Tiwi		ɰ					M
Mawng		ɰ					M
Iwaidja		ɰ					M
The Daly Languages							
Ngan'gityemerri	β	ɣ		ʒ		ʒ	I M
Marrithiyel	β	ɣ	ð	ʒ		ʒ	I M
Marrany	β	ɣ		ʒ		ʒ	I M
Marringarr	β	ɣ		ʒ		ʒ	I M
Marramaninjsji	β	ɣ		ʒ		ʒ	I M

^a

Other languages predominantly from Queensland include: Anguthimri, Awngthim, Aritinngithigh, Luthigh, Mbiywom, Yinwum, Wuthati, Uradhi, Ngkoth, Umbuygamu, Kuku-Thaypan, Kunjen, Kurtjar, Gugu Warra and Lama-lama. These each have 3 fricatives [β, ɣ, ð] (many of these are extinct, however) (Butcher, forthcoming).

^b

Initial, Medial or Final

4.2 Nasals in Australian languages

Australian languages have a very rich inventory of nasals with most languages having a matched nasal to every oral stop at each place of articulation (see Dixon, 1980 pp. 139-144 and O'Grady et al., 1966, for more on this topic). In a comprehensive phonological survey of Australian languages reported in Hamilton (1996), all have a phoneme inventory with oral stops and nasals matched at all places of articulation. Bininj Gun-wok follows this pattern and phonotactically nasals can be found in both syllable onset and coda positions (see the syllable structure shown in Expression 1.2 on page 20). Nasals are not attested as occurring in a syllable nucleus as a 'syllabic' nasal (Evans, 2003), and there is no evidence of this phonetically in fast connected speech.

How are these many places of articulation kept distinct in Bininj Gun-wok and Australian languages more generally, considering that, as discussed above in § 3.1, place of articulation cues are acoustically masked in nasals? One possible strategy is to delay the lowering of the velum, consequently delaying nasalisation.

It has been observed that there is little or no anticipatory nasal co-articulation in many Australian languages (Butcher, 1999). Nasalisation occurs when the velum is opened in anticipation of a phonemically nasal segment. Rather than anticipatory nasalisation, velar lowering is delayed until the last possible moment after the articulatory closure amongst Australian languages. The result is that in a sequence of a vowel followed by a nasal consonant (VN sequence) there is often some prestopping of the nasal. In other words there is a very brief oral stop found immediately after closure of the primary articulators in a nasal, at the offset of the previous vowel and before the lowering of the velum for the nasal articulation. This observation has led to the development of the hypothesis that a delay in velar lowering serves to preserve place of articulation cues (Butcher, 1999; Fletcher, Butcher, Loakes, & Stoakes, 2010). This is particularly

important for a language with many contrastive places of articulation.

4.3 The place of articulation imperative and the medial position

The word medial position is a position of relative privilege amongst Australian languages. The majority of phonetic contrasts in Bininj Gun-wok occur in this word medial position which is not unusual amongst languages of the area. Butcher (2006a) has investigated a number of features that are common to the languages of Australia, which when considered together, show that speakers may favour place of articulation cues over manner of articulation cues particularly in a word medial position. He has termed this the ‘Place of Articulation Imperative’ which has its basis in extensive qualitative and quantitative research across a representative sample of Australian languages (see § 1.4 para. 1 for a survey) (Butcher, 2006a, forthcoming). A hypothesis central to the theory is that in order to keep many places of articulation distinct, anticipatory nasal coarticulation—or manner assimilation—must be avoided.

To summarise some key background to the theory; Butcher describes the phoneme inventories of Australian languages as ‘long thin’ phonologies. This is in contrast to the phonologies of the majority of the world’s languages. Australian languages show a reduced set of manner of articulations and an enhanced set of place of articulation contrasts. As discussed above in § 1.3 Bininj Gun-wok, as with many other Australian languages, lacks phonological fricatives and affricates. In general Australian languages do not have voicing contrasts in stops but nasals are well represented in the lexicon and can be found in all positions within a syllable.

Butcher (1995) says that when viewed together, these phonological aspects of Australian languages are essential for enhancing the perceptual cues for place of articulation or at least minimising the chance to obscure them. Con-

sonants transitions contain the majority of the place of articulation cues. In order to keep medial consonants perceptually distinct the transitions are protected from coarticulatory effects, particularly within the coronal phonological class (Butcher, 1995).

When considering the languages from outside Australia however, Ohala and Kawasaki (1984) say that “[i]n general, languages have more distinct syllable onsets than they do codas...” (Ohala & Kawasaki, 1984, p. 115). They go on to say that CV syllables have greater salience than VC syllables due to the fact “...that assimilation (coarticulation) is predominantly anticipatory rather than preservatory (i.e. regressive as opposed to progressive)” (Ohala & Kawasaki, 1984, p. 117 citing Javkin, 1979). Recasens (2004, p. 435) cites Ohala and Kawasaki (1984) and states, “[i]t is known that consonants are subject to more articulatory reduction syllable finally than syllable initially”. These statements do not describe the phonetic situation within Australian languages.

Australian languages have a documented diachronic loss of word-initial consonants that has occurred independently in a number of languages particularly Arrernte, a Pama-Nyungan language spoken in Central Australia (Breen & Pensalfini, 1999; Dixon, 2002). This initial consonant loss is also attested in some of the languages of Cape York Peninsula (see Hale, 1976; Sommer, 1970). In Gundjeihmi (Bininj Gun-wok) and to some extent, the Kuninjku and Kunwinjku varieties, there is also weakening or deletion of initial consonants. There is also neutralisation of some of the marginal contrasts in the word initial position for example retroflexes are often neutralised to plain apicals. Evans (2003, p. 96) says this initial dropping—particularly common of initial velars /ŋ/—is an areal feature that is found in many of the languages spoken in Northwestern Arnhem Land. As one moves from east to west in the Bininj Gun-wok dialect chain there is an increase in prevalence of /ŋ/ dropping word initially (see Map 1.1) (Evans, 2003).

Clusters in Bininj Gun-wok tend to agree for retroflexion and in a cluster an

apical consonant—either a stop or nasal—will not be followed by a post-apical (retroflex) consonant and if a post-apical consonant is in a cluster with another coronal then the following consonant will also be retroflex. It is unclear if this is at a lexical level or if this a form of place assimilation.

It has been reported that in many languages that the word initial position is often strengthened. In many languages word initial phones have many phonetic cues that are strengthened (Cho & Jun, 2000; Cho & Keating, 2001; Fougeron & Keating, 1997; Keating, Cho, Fougeron, & Hsu, 1998, 2004). This strengthening effect occurs at the start of both words and utterances and results in—amongst other things—longer VOT values. There is also evidence for longer and stronger closure phases which have been measured directly by dynamic electropalatography (Cho & Keating, 2001). Fougeron and Keating (1997) argue that syllable onsets are less variable than syllable offsets. This tendency is very much reversed in Australian languages and further cross-linguistic research is needed to ascertain whether initial strengthening is a universal. The data from Australian languages shows that it is more common for weakening in this initial position than strengthening. This initial weakening has the corollary of final strengthening in the word medial—or syllable final—position. This final strengthening is highly uncommon cross-linguistically and this study will lay down the foundations for further investigation into these effects.

The hypothesis that there is some kind of strengthening in word medial position relates directly to the previous descriptions of fortis and lenis consonants. There is limited evidence that in Bininj Gun-wok the medial position is strengthened rather than weakened and the evidence for this is the number of contrasts found in this prosodic position. Fortis stops are found in the word medial position and the phonetic correlates of strength of articulation will be investigated further in the first two experimental chapters of this study (Chapter 6 and Chapter 7).

Returning to the Place of Articulation Imperative, there is an increasing

amount of experimental phonetic evidence to support Butcher's observations regarding the importance of place of articulation in Australian languages. Arrernte, Yanyuwa and Yindjibarndi, have all shown to have spectral cues that aid the identification of place of articulation. These cues are as tightly controlled in medial vowel and consonant (VC) sequences as they are in consonant and vowel (CV) sequences (Tabain, Breen, & Butcher, 2004). This claim is supported by Graetzer (2012) in four Australian languages (Arrernte, Burarra, Gupapuyngu and Warlpiri). The results are in contrast to English that shows more stability in spectral cues of CV consonant sequences (Tabain et al., 2004). Furthermore, a number of Australian languages show a resistance to place assimilation in clusters of two stops and this has been shown experimentally using a number of articulatory techniques, primarily electropalatography (Butcher, 1996; Fletcher et al., 2010, 2011). Furthermore, there is a resistance to medial VC nasal and lateral assimilation (Butcher, 1999; Butcher & Loakes, 2008; Loakes et al., 2008).

Graetzer (2012) found that anticipatory vowel-to-consonant coarticulation exceeded carry-over coarticulation for the non-Arandic languages in the study. These were Burarra, a Non-Pama-Nyungan language, and Gupapuyngu, a language within the Yolngu Matha group with a medial stop contrast and phonological vowel length. Although Gupapuyngu is classified linguistically as a Pama-Nyungan language there is significant contact with the neighbouring Non-Pama-Nyungan languages at a time-depth that is unknown. Still more research is needed to thoroughly investigate the extent of anticipatory coarticulation in the medial position.

In addition to resistance to place assimilation there is also a widespread resistance to anticipatory assimilation of nasalisation (manner of articulation) within Australian languages. This is most obvious in languages that have an avoidance of nasal anticipation encoded in their phonologies. Phonologically prestopped nasal segments are rare crosslinguistically and have only been de-

scribed phonologically in Australian languages such as Arrernte and Diyari (Dixon, 2002; Ladefoged & Maddieson, 1996; Maddieson, 1988, 1989; Maddieson & Ladefoged, 1993). Hercus (1972) notes that there is phonological prestopping of nasals and laterals in Arabana-Wannganyuru. Additionally there is phonetic prestopping observed in the numerous Yolŋu Matha (languages), including Gupapuyŋu, Djambarrpuyŋu, Gumatj, as reported by Butcher (2006a).

Prestopped nasals are a common feature of many Australian languages both phonetically and phonologically (Butcher, 1999; Butcher & Loakes, 2008; Loakes et al., 2008). In Arrernte (Breen & Dobson, 2005), there is “... very strong evidence that these sounds arise from an original lengthened or geminated nasal” and interestingly nasal prestopping is blocked by the presence of a preceding nasal in the same word (Butcher, 2006a). Phonetically, nasal prestopping is due to a delay in velum lowering which is thought to be under direct muscular control. The phonological motivation for this kind of delay is to enhance the transitional place of articulation cues between the vowel and the nasal.

Butcher has tested the possible perceptual basis of the claim that, for speakers of Australian languages, place of articulation is easier to perceive than manner of articulation. Miller and Nicely (1955) found in a perceptual study of English speakers, that manner of articulation was easier for listeners to discriminate than place of articulation when presented with stimuli embedded in various noise conditions. In contrast a perceptual study presented to speakers of an Australian language (first language speakers of Yolŋu Matha (Djambarrpuyŋu dialect)), the listeners found it easier to discriminate place of articulation rather than manner of articulation under various noise conditions (Stoakes, Butcher, Fletcher, & Tabain, 2012). Despite the results, there were a number of unavoidable methodological problems with the Australian study, however. Mainly that the noise conditions were not randomised which introduced a learning effect. Further perceptual work with speakers of Australian languages is needed in order to investigate how these perceptual cues to consonant identity are perceived

by speakers of other Australian languages.

The debate regarding the difference between medial stops in a great variety of Australian languages provides crucial background to understanding the nature of the contrast in Bininj Gun-wok. The medial position is the site of so many of the important phonetic contrasts in Australian languages. Before presenting the experimental results a short description of Bininj Gun-wok consonants is presented to provide essential background to this study.

4.4 The phonetics of consonants in Bininj Gun-Wok

This brief introduction to the phonetics of Bininj Gun-wok is based on previous research on the language (see Butcher, forthcoming; Capell, 1942; Carroll, 1976; Evans, 2003; Jernudd, 1974) and in addition some initial impressionistic observations by the author. This description supplements the phonemic inventory and phonological description of Bininj Gun-wok presented above in § 1.3. These observations should be taken together with the quantitative analysis to provide a more thorough description of the language.

Rather than dividing this description by manner of articulation, this phonetic illustration uses place of articulation to class the phones and allophones (see § 1.1). Regular phonetic voicing contrasts have not been previously described in Bininj Gun-wok and voicing will not be discussed further in this section. The phonetic realisations of the vowels are also not described here. For more information of vowels refer to previous studies regarding the vowels of Bininj Gun-wok (see Fletcher & Butcher, 2002, 2003; Fletcher et al., 2007). Also refer to the vowel phonology detailed above in § 1.3.1.

Many of the consonant articulations presented below have been described in detail for other Australian languages. As discussed above, Australian languages are reported as phonetically homogeneous. However, this statement obscures the reality that there are a wide range of phonetic realisations requiring fur-

ther description. The articulations and allophonic variation detailed below are provided primarily to aid the interpretation of the results in the remaining chapters.

Synchronic weakening or lenition is a feature of the phonetic realisation of consonants in many Australian languages. All obstruents in Australian languages undergo some form of lenition in certain prosodic positions and found commonly in connected speech. Butcher (1996) observes that all peripheral stops are liable to be affected by lenition, and in a wide variety of Australian languages a single stop is often realised as an approximant. This is in allophonic free variation but there is some contextual regularity which suggests that it could be dependent on syllable position. In addition, apical stops ([t,d,t̪,d̪]) specifically, can become taps or flaps [ɾ,ɽ] or are subject to lenition to approximants [ɹ,ɻ] in connected speech. How these lenition processes affect fortis stops will be investigated and discussed with regard to the experimental data in the following chapters.

4.4.1 Peripherals

The peripheral phoneme class includes bilabials and velars and the motivation for grouping them together is discussed further in § 1.3. Bilabials in Bininj Gun-wok can be articulated as obstruents (oral plosives) or nasals. Bilabial stops are commonly realised as voiceless stops [p] in utterance initial position, but intervocalically it is commonly articulated as a fully voiced stop [b]. The lenis articulation ranges from a voiceless stop to a fully voiced stop and for some speakers they can be realised as a bilabial approximant [β] or even with some slight frication [β̞] in connected speech. The fortis intervocalic stop [p:] is generally voiceless with a longer closure duration than the lenis. Nasals are voiced and articulated at the same place of articulation [m].

The velar stop can be voiceless [k] or voiced [g] and articulated toward the posterior of the vocal tract by Kunwinjku speakers and in some environments—

particularly between high back rounded vowels—should be phonetically described as uvular [q] as noted by Butcher and Tabain (2004) in a number of Australian languages including Bininj Gun-wok. This tongue retraction seems to be an allophonic variation and is not phonemically contrastive. Carroll (1976, p. 13) describes these sounds in Kunwinjku as dorso-velar which matches the descriptions of other languages in Butcher and Tabain (2004). The tongue body is retracted making closure with the back of the soft palate. As with the bilabial lenis stops, velar lenis stops can be articulated as an approximant [ɰ] or for some speakers a voiced fricative (or more specifically a raised approximant) [ɣ,ɰ]. The fortis stop [k:] is voiceless and has a long closure duration. Velar nasals as with the nasals at the other places of articulation are exclusively voiced [ŋ].

A characteristic of velar articulations cross-linguistically is a double release burst (Keating, Westbury, & Stevens, 1980; Kingston, 1983). This double—or sometimes triple—burst occurs when the tongue is furthest back in the mouth and in an almost uvular configuration, which is common in non-front vowel environments in Bininj Gun-wok. When a speaker is articulating a velar the precise point of closure is a thin band of the tongue dorsum and with incomplete stricture the air escapes in a rapid and turbulent manner. Keating et al. (1980) argue that multiple release spikes are the result of an aerodynamic effect—a Bernoulli force similar to the one that draws the vocal folds together in voicing—occurring between the tongue dorsum and the soft palate. The double spike does not appear at other places of articulation although sometimes a faint second burst can be observed on the spectrogram in bilabial fortis plosives and it is possible that a similar aerodynamic effect is at work in these articulations.

Velar stops found in the initial position are remarkably variable with regard to the degree of anteriority of the tongue. Butcher and Tabain (2004) note that when examining the static palatograms gathered by Jernudd (1974), “...it seems quite probable that Jernudd’s broken lines [seen below in Figure 4.1]

represent lack of contact at the midline in some repetitions, suggesting that there was no complete closure for the articulations in question”.

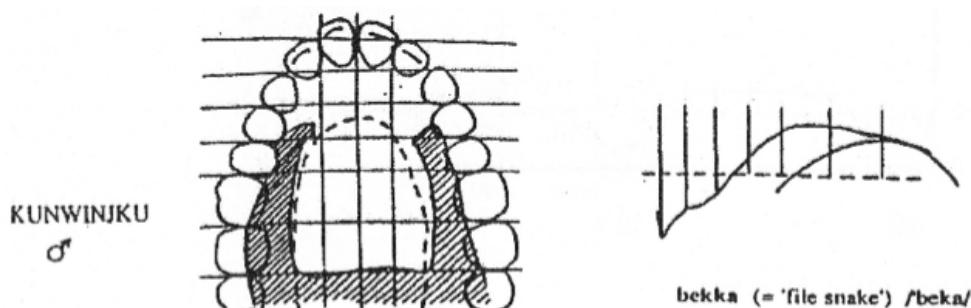


FIGURE 4.1: Static palatogram showing the tongue shape for the velar tense stop [k:] in the word *bekka*, ‘file snake *Acrochordus arafurae*’, from Butcher (forthcoming).

The labio-velar approximant [w] is particularly unstable in syllable or morpheme initial position and especially in the Kuninjku (eastern Bininj Gun-wok) variety can be subject to deletion. This phenomenon as is evident in the names of the Kunwinjku vs the Kuninjku varieties, with the /w/ deleted in the initial position of the root *winjku* in the latter variety.

4.4.2 Coronals

The coronal phonemes include those that raise the tip or blade of the tongue toward the hard palate and they are realised at three places of articulation in Bininj Gun-wok. Ladefoged and Maddieson (1996, p. 98) note that closure durations for single coronal stops can be extremely short and this is true of many of the apical coronals in this study.

The apical class of obstruents are those that involve the tongue tip as the active articulator. Bininj Gun-wok has two apical places of articulation, apico-alveolar [t,t̪,n,l,r] and apico-postalveolar [t̪,t̪̠,n̪,l̪,r̪], which display the majority of manner of articulation contrasts in the language at five. According to Carroll (1976, p. 11), for the Kunwinjku variety of Bininj Gun-wok, the apico-alveolar consonants—both obstruent and nasal—have the main contact made

with the apex of the tongue just anterior to the alveolar ridge and posterior to the upper teeth. This description is presumably based upon the static palatographic data gathered by Jernudd (1974), although this is not explicitly stated in the text by Carroll (1976). Jernudd's palatograms have been redrawn and a selection can be found in Butcher (1995) comparing coronal articulations in Kunwinjku with those in other Australian languages. The palatograms for some articulations made by Kunwinjku speakers are reproduced in Figure 4.2.

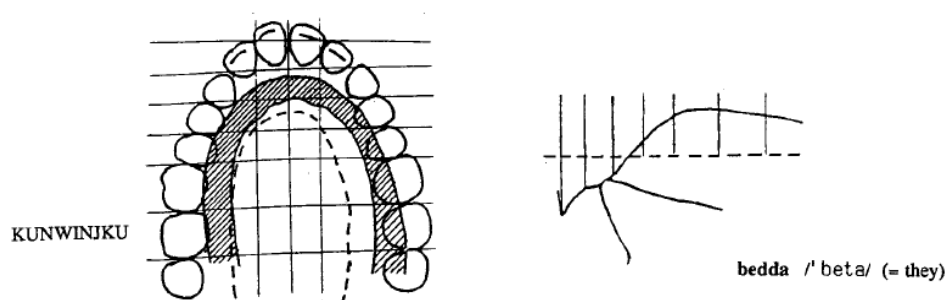


FIGURE 4.2: Static palatogram of a Kunwinjku utterance *bedda* 'they', showing tongue shape in the apico-alveolar stop, from Butcher (1995) redrawn from Jernudd (1974).

The realisation of apico-postalveolar consonants, in contrast, has the tongue tip drawn back and making contact in the post-alveolar region behind the alveolar ridge. The release occurs when the tongue is drawn forward in a movement that has been described as ballistic retroflexion (Baker, 2008, p. 20). Jernudd's (1974) static palatographic data shows that apico-postalveolar consonants are often realised using a sub-laminal gesture and this has been confirmed by Butcher as well as by the author, in consultation with the Kunwinjku speakers involved in the current study. This sub-laminal retroflexion is neutralised word-initially, however (see below). It is for this reason that the term retroflex is used interchangeably with apico-postalveolar in the experimental chapters as there is a high degree of allophonic variation.

There is a distinction found within coronals for both laterals and retroflexes. Both the apico-alveolar [l] and the apico-post-alveolar [ɭ] lateral are articulated at the same place of articulation as their stop equivalent. In general, laterals

occur in similar distribution to nasals.

As with the labio-velar approximant [w], the palatal approximant [j] can be entirely elided in connected speech (Butcher, 1996). This happens particularly if the following vowel is [ʊ] in the case of [w] or [ɪ] in the case of [j]. In these environments the vowel is lengthened.

As mentioned above, in initial position the contrast between alveolar and post-alveolar stops tends to be neutralised and the apico-alveolar is the most common realisation for initial post-alveolar stops. This positional effect has been noted by Carroll (1976), Butcher (1995), Hamilton (1996, p. 38) and Evans (2003). Neutralisation is found in both the post-alveolar stops and of post-alveolar laterals. Apico-postalveolar nasals have not been attested word initially in the current study so it is assumed, but not confirmed, that these too follow a similar pattern.

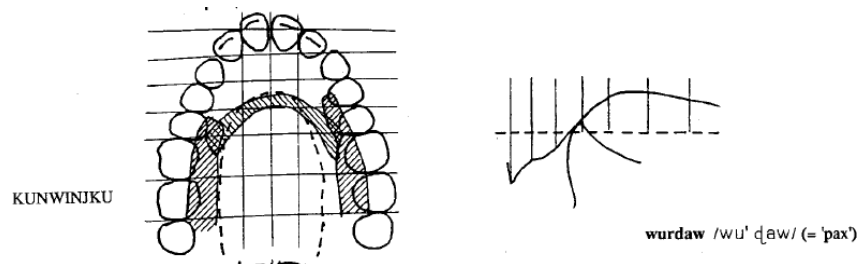


FIGURE 4.3: Static palatogram of a Kunwinjku utterance wurdaw 'pax', showing tongue shape in the apico-post-alveolar stop, from Butcher (1995) redrawn from Jernudd (1974).

Within the rhotic phonological class there is significant variation in the phonetic realisation. The tap [ɾ] is articulated at the apical-alveolar place but is has been observed by the author to occur as an apical-post alveolar [ɽ] for some speakers. There may be neutralisation found at this place of articulation but this has not been confirmed for the speakers in this study. The apico-alveolar tap is sometimes articulated as an apical trill [r] but acoustic analysis shows that in connected speech it is commonly articulated as a single repetition of the tap. This is beyond the scope of this study, however.

The articulation of the lamino-palatal [ɕ] stop involves a greater surface

area of the tongue during articulation when compared to the other places of articulation in Bininj Gun-wok. The advanced diacritic is placed below the palatal plosive to indicate that the tongue is pushed forward making the closure more anterior. In the lamino-palatal articulation, the blade of the tongue makes broad contact at or in front of the hard palate, just behind the alveolar ridge with the apex of the tongue often projected forward between the teeth. The closure can be described as anterodorso-palatal, or more precisely anterodorso-pre-palatal for some speakers, using Catford's (1988) classification. The lamino-palatal is very different from the other stops in terms of the release characteristics. The release phase shows a high level of frication with a long and strident burst. Stops release at other places of articulation, in contrast have a short burst followed by very low amplitude frication before voice onset.

Observationally, when pronouncing lamino-palatals Kunwinjku speakers generally form the constriction with the tongue blade just behind the alveolar ridge, as previously described in related languages (Butcher, 1995). At times the tongue tip is seen to be interdental and distributed, due to the forward projection of the tongue body. Based upon these observation and previous reports by other researchers, the articulations may be more properly described as lamino-post-alveolar rather than lamino palatal, indicating this relatively anterior place of articulation (Jernudd, 1974).

Oates (1964, p. 11) in a phonetic survey of Bininj Gun-wok, identified an additional laminal at the palatal place of articulation which she terms alveopalatal. Neither Jernudd (1974, p. 84) or Carroll (1976, p. 14) find this phoneme amongst the items recorded in their studies. This additional laminal was not noted to be present in data collected for the current study.

4.4.3 The glottal stop

The glottal stop is an unusual phoneme in Bininj Gun-wok and is restricted to syllable final position. This phonotactic constraint means that it is unclear

whether the glottal stop achieves full segmental status. It may be better described as some form of boundary marker or autosegmental phonological feature as discussed by Baker (1999). Harvey (1991) lists a number of languages found in the Northern Territory that are analysed as having the glottal stop as a distinctive segment. The languages include Gamu, Gunwinjgu [Kunwinjku], Jawoyn, Mangarrayi, Ngalakgan, Ngandi, Rembarrnga, Wagiman and the Yolngu languages. Harvey has proposed that the glottal stop could be classed as a stop that is unspecified for place of articulation (Harvey, 1991). The positional restriction that prevents glottals from occurring in adjacent positions to stops could indicate an interaction between glottal stops and fortis stops. From a phonotactic perspective glottal stops only occur after continuants.

4.5 Aims, hypotheses and research questions

The primary aims of the first two experiments of this study are to investigate whether there are measurable differences in articulatory or respiratory strength between lenis and fortis stops and to describe voicing patterns in medial stop consonants.

Phonologically, Bininj Gun-wok medial stops have a contrast that is primarily based on length and this has been widely observed across the dialects. In Bininj Gun-wok stops articulated at same place articulation contrast phonologically for length. This is not a highly productive contrast lexically however. The only attested minimal pair is between two nominals containing post-tonic stops at the velar place of articulation. These are *njarlkkan* ['ɲɛlk:ɛn] 'orchid sp.', (*Cymbidium canaliculatum*), the juice of which is used as a natural fixative for pigment in bark painting (Nabulwad, pers. comm., Oct, 2007) and *njarlkan* ['ɲɛlɣɛn] 'archerfish' (possibly *Toxotes chatareus* (Maralngurra, pers. comm.)).² As previously discussed, fortis stops are far less common in the lex-

²see Allen, Midgley, and Allen (2002, p. 251) for a description.

icon than lenis stops. The most lexically frequent configuration of consonants word medially are heterorganic clusters involving nasals and these are investigated further in Chapter 9.

To proceed with the analysis it is essential that clear hypotheses are proposed with regard to describing a quantifiable phonetic baseline for medial contrasts. The first experiment (reported in Chapter 6) examines duration and then continues by examining some non-temporal characteristics of medial stops. All measurements are done with reference to previous studies of geminates and stops in lenis/fortis opposition (see § 2.1 and § 2.2 above). Additionally, differences within the ‘long’ stop category are explored to see if there is any grounds for treating them as clusters. As discussed earlier, there has been significant debate as to the whether there is any phonetic differentiation between a phonological long stop and a geminate. It is the general consensus in the phonetic literature that regardless of the processes that form a long stop, the phonetic realisations are the same. In order to do this the fortis category is examined in greater detail in order to ascertain whether this is a single category or a group of overlapping categories. The second experimental chapter uses aerometry to investigate the aerodynamic characteristics of the same set of stops and the phonetic correlates of the lenis and fortis phonological categories and additionally explores voicing and laryngeal timing in lenis and fortis stops. The third experimental chapter also primarily utilises aerometry as the experimental technique and turns the attention to coarticulation in nasal stops and clusters. The levels and directionality of nasal coarticulation are investigated for each place of articulation in Bininj Gun-wok. This chapter provides methodological background for the experiments in the current study and elaborates on the prior literature surveyed in the previous chapters.

The central research questions (Q) and hypotheses (H) for Chapters 6, 7, 8 and 9—reporting experiments 1,2 in the initial three chapters and experiment 3 in Chapter 9—are as follows:

Experiment 1. Q1. What are the durational acoustic differences between lenis and fortis stops in Biniŋ Gun-wok and is duration alone sufficient to show a difference between the stop types?

Q2. What are the non-durational acoustic differences that cue a difference between lenis and fortis stops?

H1. Duration is the only reliable acoustic phonetic difference separating lenis and fortis stops.

H2. Voice onset time and voice termination time are not sufficient as phonetic cues to a difference between the stop types.

Experiment 2. Q1. Are there aerodynamic differences between lenis and fortis stops and additionally what are the patterns of laryngeal timing and voicing?

Q2. Is there evidence of any evidence for a difference in tension at the larynx preceding and following both lenis and fortis medial stops?

Q3. Is there any evidence for an active glottal abduction gesture in either lenis or fortis stops?

Q4. Is there any difference between the lenis and fortis stops that is dependent on place of articulation and are there any differences between the coarticulatory effects of lenis and fortis stops and the surrounding segments?

H1. There is an aerodynamic or articulatory difference between stops within the long stop category that separates fortis stops from geminates (homorganic inter-morphemic clusters).

Each of these questions and hypotheses are investigated across Chapters 6, 7 and 8. Initially the differences between lenis and fortis are examined acoustically (Chapter 6) and aerodynamically (Chapter 7). These techniques are then combined to look more closely at clusters of stops and particularly if there are any differences between fortis stops and geminate stops (Chapter 8).

For the investigation into nasal coarticulation presented in Chapter 9, some some further hypotheses are proposed:

Experiment 3. Q1. What are the patterns of nasal coarticulation found in Bininj Gun-wok nasals?

- H1. Based on studies of other Australian languages (Butcher, 1999), Bininj Gun-wok speakers delay velum opening until coincident with, or just after the onset of the supra-glottal occlusion.
- H2. There is delay in nasalisation that possibly serves to enhance place of articulation cues found in the transition from vowel to nasal Butcher (2008); Fletcher, Loakes, and Butcher (2009); Loakes et al. (2008).

The following chapter describes the methodology for the quantitative experiments and investigates the phonetics of established phonological schemata for classifying consonants in Bininj Gun-wok. In the introduction and review of the literature, previous descriptions of consonant articulation in Australian languages are introduced and a cross-linguistic comparison of stop articulations is made. The phonetic parameters for differentiating the two stop series in Bininj Gun-wok are explored in the experimental chapters *An acoustic analysis of stops* Chapter 6, Chapter 7 *An aerodynamic analysis of stops*). The differences between stops with a long duration are explored in Chapter 8, *Geminates, clusters and medial voicing*. Chapter 9—*Nasal coarticulation: an aerodynamic analysis*, looks at medial nasals and nasal cluster with a particular emphasis on nasal

coarticulation by measuring levels of nasalisation in the segments surrounding a medial nasal. Both the durations of single stops and clusters and also the levels of peak nasal air-flow are measured. The unifying theme behind the entire thesis is the hypothesis that phonemes in the medial position are privileged in Biniŋ Gun-wok.

Chapter 5

General method and statistical tools

The collection of speech data for all experiments employs the same general methodology, however each experiment uses specific materials and a specialised set of analytical tools. The methodology for each experiment and the accompanying reporting chapters is outlined below in §§ 5.6, 5.7, 5.8 and 5.9. In the first experiment (Chapter 6), the acoustic parameters for the lenis and fortis phonological categories and those acoustic parameters that correlate with an auditory impression of ‘degree of voicing’ are investigated. The results of a durational analysis are presented so as to be able to more fully explore the aerodynamic results. The results are then reinterpreted and extended using an aerodynamic analysis in the next experimental chapter (Chapter 7). Geminates and patterns of voicing are examined in Chapter 8. The fourth and final experimental chapter (Chapter 9) is a complementary aerodynamic analysis of medial nasal consonants in Biniŋ Gun-wok looking at levels of anticipatory and carry-over nasalisation and the associated timing of velar coarticulation. Additional information regarding the background and method of the nasal airflow experiment can be found in § 5.9. This chapter provides information about the construction of the corpus, including recording techniques, labelling criteria

and choice of measurements.

5.1 Linguistic material

Two corpora form the core for the analysis in the experimental chapters.¹ The first corpus, recorded by Andrew Butcher in Maningrida in October of 1990, comprises audio recordings of five speakers of the Kuninjku dialect of Bininj Gun-wok. This dialect is very closely related to Kunwinjku in terms of linguistic structure, although nominals are largely lexically distinct. The analysis of this corpus was incorporated into the durational measurements and additionally the locus equation investigation in chapter 5 and chapter 9. This will be referred to as Corpus I. The recordings for a single speaker (HK) and the associated word list are available online at the UCLA phonetics lab archive (<http://archive.phonetics.ucla.edu>, accessed 1st November, 2013).

The second corpus was recorded by the author over the course of three field seasons. The first season—field season one (June 2005)—was conducted in collaboration with Andrew Butcher and Murray Garde at Jabiru, Northern Territory (see map 1 in the front matter, xxiii for locations of the field sites). The second season—field season two (April–July, 2006 at Mamardawerre outstation)—represented the period in which the bulk of the aerodynamic and acoustic recordings were collected. In field season three (October 2007 at Mamardawerre outstation), a smaller articulatory word list was collected, mainly focusing on medial fortis stops and clusters. The recordings gathered as part of these expeditions were then compiled into three sub corpora. Firstly, a set of acoustic recordings, secondly, a set of aerodynamic and electroglottographic recordings concentrating on the fortis and lenis opposition and finally a further set of acoustic and aerodynamic recordings that focus on nasal articulation and coarticulatory effects in medial clusters. Collectively these will be

¹The word lists for Corpus I and Corpus II can be found in Appendix B.

referred to as Corpus II.

Each of the corpora used in this study consists of recordings of real words as spoken by native speakers of Bininj Gun-wok (see the information regarding speakers below). The word lists used as a basis for the recordings were constructed by the author using a word list devised by Andrew Butcher with reference to an unpublished version of Murray Garde's Kuninjku dictionary (Garde, in press) (see § 5.2.1 for the final word selection used).² The entire list was then checked and revised by Murray Garde in consultation with Bininj Gun-wok speakers for both semantic and phonological accuracy. Other sources consulted include: a list compiled by Carroll (1976) for inclusion in the phonological description of a sketch grammar; a basic Kunwinjku dictionary (Manakgu & Etherington, 1996); materials for a Kunwinjku language course compiled by Etherington and Etherington (1998). Additional resources include Garde (2002) and Evans (2003) the wordlists were cross-referenced for accuracy. There are a number of words in Carroll (1976) that are different to those recorded in the present study, mainly correcting words that include medial fortis stops. As previously discussed in § 4.1, Carroll (1976) does not explicitly identify the fortis stop as phonemically distinct in his description of Kunwinjku. There are a number of understandable errors in the phonological transcriptions such as retroflex consonants that are not distinguished. This may be due to dialectal differences or word initial neutralisation. The full word list used in the current study can be found in the Appendix. Through discussion with my language consultants there were alterations to the initially compiled word lists, taking into account dialectal variation and socio-cultural concerns. Included words that were judged to be *manwarre*—‘rude’ or ‘restricted’—were removed to conform with cultural avoidance conventions (see Garde, 2002, p. 222 and Garde, 2008b, p. 207 for more detail on this topic). It is particularly important

²Kuninjku is a variety of Bininj Gun-wok closely related to Kunwinjku (see the map on page 7).

to older speakers that the word list used consisted of words that are considered ‘proper Kunwinjku’, (*kundangkudjikarribek*), and that the words are reflective of the language usage of the group who has clan affiliation with that geographical area—in this case Mamardawerre—rather than a variety spoken by those who are born or reside elsewhere. This posed certain limitations on the words and consequently the clusters within them that could be included in the current study.

The controlled nature of any elicitation process will produce unnatural non-spontaneous speech in some respect. In Corpus II there is a prevalence of careful, hyper-articulated speech. This is mostly found amongst the earlier recordings in the corpus and the speech became more natural as the speakers became more familiar with the speech materials and the experimental method. It was not possible to control for these factors specifically, but every effort was made to only include natural speech and discard obvious speech errors. Due to only limited literacy found amongst some of the language consultants, it was necessary to ask the speaker to repeat the phrase after verbal elicitation by the author. In some cases it was possible to use flash cards written by hand in Kunwinjku orthography as the stimuli (see §A.1). Using repetition as a method of elicitation is not ideal for a phonetic study as any mispronunciation of the target word by the elicitor (in this case the author) potentially introduces cross-linguistic interference and accommodation by the speaker. All speakers have at least some level of English competence and consequently linguistic interference cannot be ruled out.

5.2 Speakers

Corpus I consists of five speakers—three male (HK, OK and DK) and two female (MM, JM)—repeating a list of 190 words three times which ideally would give 2800 tokens (recorded by Butcher, 1990). Not all words are included for all

speakers, however, as some tokens are missing or background noise is unacceptably high for the current analysis, consequently 2658 items are included in the study, 887 of which have contain lenis and fortis stops. The remainder of the corpus contains heterorganic stop clusters and both homorganic and heterorganic nasal + stop clusters, see Appendix B.1 for the full word list included in Corpus I.

TABLE 5.1: *The distribution of tokens in Corpus I by speaker.*

<i>speaker</i>	MM	JM	HK	OK	DN	<i>total</i>
<i>n</i>	172	168	179	179	188	887

In Corpus II a total of 19 speakers were recorded in the acoustic experiments and the analysis was drawn from both the acoustic and aerodynamic recordings. The word list for this corpus was heavily restricted to examine the medial stop contrast and consequently there are far fewer words included but more repetitions of each word. Also each repetition of the word is uttered in a different repetition of the entire list. The word lists used are detailed below in Table 5.4. In the durational experiment (Chapter 6) it was possible to utilise both acoustic recordings and the audio component of the articulatory recordings as a basis for the analysis.

TABLE 5.2: *The distribution of tokens in Corpus II by speaker.*

<i>speaker</i>	AB	BD	BN	CJ	CL	CM	CN	DD	DJ	DM
<i>n</i>	36	15	90	48	55	159	24	15	35	24
<i>speaker</i>		EN	HM	IB	JD	JN	MN	RN	TD	VB
<i>n</i>		18	15	16	18	10	47	80	38	44

total n: 806 tokens

Table 5.3 gives a breakdown of the sex of the speakers who were recorded

as part of Corpus II. Two additional speakers were also recorded but their data were excluded from analysis primarily due to the acoustic recordings being unsuitable for analysis due to excessive environmental background noise rather than to any unsuitability of the speaker.

TABLE 5.3: *Distribution of speakers by sex.*

Males:		BD	CM	DM	DD	EN	IB	LL	JD	TD
Females:	AB	BN	CJ	CL	CN	HM	JN	MN	RN	VB

Of the nineteen speakers recorded, six from Corpus II were selected for further analysis. This sample included three males (CM, TD, DM) and three females (BN, RN, MN) who were chosen on the basis of having the most complete data sets. Results for these six speakers are reported in greater detail in the aerodynamic chapters (Chapter 7, Chapter 8 and chapter 9). These analyses are based on results from all speakers where there are data available, primarily as part of the durational analysis in the acoustic chapter 6.

The speakers in Corpus I are first language speakers of the Kuninjku dialect of Bininj Gun-wok, resident in Maningrida at the intersection of the Liverpool and Tomkinson rivers. All speakers in Corpus II—except where noted—identify as first language speakers of the Kunwinjku dialect of Bininj Gun-wok as spoken at Mamardawerre on the Goomadeer river. The male speakers are all aged between 30 and 60 and the female speakers range in age from 25 to 55. Some of the speakers have come to Mamardawerre through marriage (VB and LL) and may speak other languages of the area as a first language. The speaker CM is a Rembarrnga first language speaker and learnt Kunwinjku as a young child in addition to English for which he has a high proficiency.

The durational analysis (§ 6.3) the locus equations of stops (§ 6.8) and the analysis of spectral tilt (§ 8.6.1) all use audio recordings from Corpus I. This

corpus has a large number of tokens with examples of medial stops at all five places of articulation which makes it the best choice for place of articulation analyses.

The aerodynamic data are all drawn from Corpus II which is a multi-channel corpus of articulatory data. The voice analysis—which uses electroglottographic (EGG) data—contains five speakers, four male (CM, DD, DM, EN) and one female (RN) and this is drawn from Corpus II.

All consultants who took part in this study were paid for their time and gave consent for the recorded data to be published as part of academic research provided that their identities were obscured and their full names were not included.

5.2.1 The word lists

The speech materials for the first two experiments—reported in Chapters 6 and 7—consist of a list of real Kunwinjku words that contain medial stops at each place of articulation. A separate word list including nasals was used for chapter 9. The tokens recorded are either citation forms of real words uttered within a carrier phrase or isolated words repeated. The language material in Corpus I was a lexical item repeated three times in isolation. The stimuli for Corpus II were presented in a pseudo-randomised manner in the form:

- (5.1) Yuwun yiyime **bobo** yiyimen **kabo**.
 PROHIB 2/3.say.NP ‘goodbye’ 2/3.say.NP ‘green ant’
 ju:n 'i:mɛ 'bɔbɔ 'i:,mɛn 'kɛbɔ
 ‘You don’t say ‘goodbye’, you say ‘green ant’.

The same word was spoken in both focussed position—*bobo* in Example (4.1)—and also in unfocussed position—*kabo* in Example (4.1) (Butcher & Harrington, 2003a). Usually, however, most speakers separated the phrase into two separate intonational phrase each with the target word in focussed position.

Three repetitions of the entire word list were recorded on separate occasions (ideally on separate days). The first reading of the word list typically contained a higher number of speech errors and was produced at a substantially reduced speech rate. Tokens that were noticeably dis-fluent were excluded from analysis and additionally any tokens that contained a speech error, or were interrupted by background noise were also not included in the analysis.

The word lists in Corpus II were recorded on two occasions separated by 14 months for speakers CM, RN, BN and MN in July 2006 and October 2007—field season 2 and field season 3. TD and DN were recorded only in 2007—field season 3. The word list was altered slightly for the recording in field season 3, (2007). The initial recordings were captured acoustically whereas later recordings have acoustic and associated aerodynamic and laryngographic (L_x) records. The laryngographic portion of the second experiment and the results are presented in Chapter 8 on page 253 in § 8.6. A subset of the words recorded in the third season, include inter-morphemic geminates and inter-morphemic fortis stops found in similar vowel environments (see word list in § 7.2.2 and § 8.1.3).

The primary reference for developing the word lists prior to fieldwork was (Evans, 2003, p. 333). A main source that was consulted was Table 8.1 in Evans (2003, p. 333) that lists the allowable inter-morphemic stop clusters in the language.

A word list that includes incorporating noun forms with morpheme final stop consonants can be found in § 8.1.3. Incorporated noun forms combine verbs-stems and nouns-roots and this results in many clusters. The experiment controls, as far as possible, for whether a word is homomorphemic, belongs to a single morpheme, or heteromorphemic, comprises multiple morphemes. The majority of clusters found in Bininj Gun-wok are heteromorphemic. Words for body parts have yielded the richest lexicon of heteromorphemic geminate stop examples. For example, the noun *keb* ‘nose’ and *bid* ‘hand’ combine into

complex polymorphemic words that contain consonant clusters. By referring to Evans (2003), particularly Table 5.4 and § 10.4. ‘Noun Incorporation’, a list of potential words was compiled. A subset of the full word list was chosen that included tokens from all places of articulation. The long stops have examples of both inter-morphemic, (for example, /C.C/ where: /./ is a morpheme boundary and /C/ are two oral stops with the same place of articulation (homorganic)), and intra-morphemic stops which are homorganic as well as belonging to the same morphological unit (/CC/).

The stimuli used in the experiments are listed in Table 5.4 (list A),(list B) and (list C). These are repeated at the start of Chapters 7 and 8 for ease of exposition.

TABLE 5.4: *Word lists: A—fortis stops, B—lenis stops and C—geminate stops.*

ID	WORD	PHONETIC	GLOSS
A01	kabbal	[ˈkəp:əl]	<i>flood plain</i>
A02	ngabbard	[ˈŋəp:əd] [ŋəp:ə]	<i>kinship term (F)</i>
A03	kakkak	[ˈkək:ək]	<i>kinship term (MM or MF)</i>
A04	kaddum	[ˈkət:əm]	<i>above, up</i>
A05	dardda	[ˈtəɾ:ə]	<i>kinship term (YB)</i>
A06	ngalkodjdjan	[ŋəlkwɔ:cən]	<i>subsection name (Fe)</i>
ID	WORD	PHONETIC	GLOSS
B05	kabo	[ˈkəbɔ]	<i>green ant (Oecophylla smaragdina)</i>
B04	kakid	[ˈkəgɪd]	<i>middle of the night</i>
B14	kadi	[ˈkədɪ]	<i>here</i>
B11	djarduk	[ˈdʒədʊk]	<i>red apple</i>
B13	yidjare	[ˈjɪdʒɛ]	<i>you want</i>
ID	WORD	PHONETIC	GLOSS
C01	kebbaldjurri	[kəˈp:əlˌdʒʊrɪ]	<i>royal spoon bill (Platalea regia)</i>
C02	kebbalhmeng	[kəˈp:əlˌmɛŋ]	<i>close your nose</i>
C03	kebberrrelh	[ˈkəp:ɛrɛlʔ]	<i>flat nose</i>
B01	bakbakkeng	[bəkpeˈk:ɛŋ]	<i>break into pieces</i>
D03	nakukkimuk	[nəˈgʊkɪˌmʊk]	<i>big man</i>
D04	kukkimuk	[ˈgʊkɪˌmʊk]	<i>very big</i>

The analysis for Chapter 7 uses the words in List A and List B, whereas the analysis for Chapter 8 uses words taken all three lists (A, B and C). A separate word list was used for the experiments that focus on nasal consonants. This list

can be found in § 5.9 on page 161.

The complete word list can be found in the Appendix (Appendix B.1—Corpus I and Appendix B.2—Corpus II). Not all words in the complete word list are included in the analysis however, as not all of these lexical items contain the phonemes under investigation (lenis and fortis medial stops for example).

5.3 The recording method

Corpus I was recorded under field conditions using a high quality magnetic cassette tape recorder (*Sony TCM-5000*) with a ‘boundary effect’ microphone (*Sony ECM-D8*). These were subsequently digitised at a 22.05 kHz sample rate and a bit depth of 16 bits. The recordings for Corpus II were recorded outside at the field site in a quiet part of the camp adjacent to a corrugated-iron school building. Wind noise was controlled as much as possible by setting up barriers and in addition acoustic reflections from the adjacent building was minimised using foam baffling. All acoustic signals—in particular those later analysed spectrally—were recorded, using a *Sony ECM-MS957* electret condenser microphone and recorded onto a *Marantz PMD690* portable flash recorder, as mono, uncompressed Broadcast WAV files at a 48 kHz sample rate and a bit depth of 16 bits. The aerodynamic data were recorded at a lower sample rate of 11 kHz, with a bit depth of 16 bits. This lower sound quality precluded its use in a spectral or formant analysis. These data have been included in the burst amplitude analysis, however (§ 6.7.1). In the durational analysis both the acoustic-only recordings and the acoustic track from the physiological recordings were included in the durational analysis detailed in § 6.4.

The physiological recordings (Corpus II) include aerodynamic recordings that measure changes in the rate of flow of air released from the lungs through the oral and nasal cavity. In addition intra-oral pressure is included for some of these recordings. The aerodynamic recordings provide multi-channelled physi-

ological data and form the basis for the analyses found in Chapter 7 on page 223, Chapter 8 on page 253 and Chapter 9 on page 275. The method and details of the instrumentation used for the data capture and subsequent analysis of these aerodynamic data is presented in § 5.7.1 on page 135.

5.4 Analysis

The analysis procedure was different in each of the experiments. Many aspects of the methodology are shared and could be standardised across all of the experiments. All data were broadly segmented into utterances from the original digital audio file automatically using a computer script. These individual utterances—either the word in a carrier phrase or three repetitions of the token—were then phonetically labelled by hand using *Praat*, software for the analysis of speech. These labelled data were then hierarchically associated within The Emu Speech Database (Boersma & Weenink, 2013; Bombien, Cassidy, Harrington, John, & Palethorpe, 2006; Cassidy & Harrington, 2001; Harrington, Cassidy, John, & Scheffers, 2003), another speech analysis program. The hierarchical organisation of the labelling is integral to the analysis and this was achieved using Tool Command Language (TCL) scripts developed by the Emu Development Team. A number of different labelling tiers were used to indicate certain aspects of the speech signal. The labelling criteria and additional annotation are discussed further in § 5.4.1.

All subsequent signal and statistical analysis was done within the *R* software environment (Ihaka & Gentleman, 1996) using the *EMU – R, 4.2* interface which allows *R* direct access to the *Emu* database. This interface allows complex compound querying of the corpus and the extraction of acoustic track data for analysis within *R*. Other signals that can be analysed include fundamental frequency (F_0) and physiological information, such as oral flow rate (U_o). The statistical analyses and data visualisation is all handled within the *R* environ-

ment. Automatic calculations of local maxima and minima was performed by computer script.

5.4.1 Labelling and segmentation

Each experiment has specific labelling requirements based on the acoustic and articulatory channels used. For the analysis in Chapter 6 the main phonetic landmarks were labelled based on the acoustic signal. These were hand labelled on separate tiers, a broad phonetic segmentation tier, named *phonetic* and a *qualitative* tier that records information such as voicing, voice quality and other phonetic observations with a domain larger than a single segment. This *qualitative* tier also contains the labels for the burst, voice termination time and the voice onset time. Additional tiers contain event markers that align to the maxima and minima of various phonetic parameters such as fundamental frequency (F_0), amplitude, flow and pressure extrema.

The sound files were hierarchically associated in *EMU* using computer scripts incorporated within the *Emu Speech Database* package. These scripts parse the phonetic labelling onto a phonemic tier using a user generated dictionary. The resulting files can then be split into syllables, words and utterances. This hierarchical organisation of the information allows for complex querying based upon a segment's position within the morpheme, word or utterance.

5.4.2 The annotation criteria

All annotations are done using a combination of spectrographic analysis and with reference to a synchronous sound pressure waveform (see Figures 5.1 and 5.2 below). This is in addition to an initial auditory analysis. The total consonant duration is taken as the time from the onset of the closure to the onset of regular voicing in the following vowel. The moment of closure is taken to be the time at which the higher frequency sounds are dampened, which is visible on a spectrogram. The onset of the following vowel is the time at which there

starts to be excitation in the higher frequencies. In order to measure the VOT, a marker is placed at the release of the articulators with reference to the beginning of the burst. Another marker was placed at the onset of regular voicing of the following vowel, again at the time when there is excitation in the higher frequencies. The total *closure* duration is the total consonant duration less the duration of the VOT. Voice termination time (VTT) is measured as the perseverance of voicing after closure of the articulators within the stop. In fully voiced stops voicing persists on through the entire closure whereas in voiceless stops it extends only part way into the closure.

Figure 5.1 shows an example of a intervocalic lenis, voiced stop (a bilabial approximant [β] or very lenited voiced stop [b], found in the word *bobo* ‘good-bye’). The speech sound pressure waveform, spectrogram and the associated labelling tiers show the standard segmentation used in this study. In the example (Figure 5.1) the glottal pulsing extends through the entire closure period. In this word, a stop is regularly realised as an approximant with no clear release burst. This is however in free-variation with clearly fully-voiced and voiceless plosives. The segmental analysis is shown on the *Phonetic* tier and further diacritics and voicing is shown on the *Qualitative* tier.

Some voiced stops exhibit clear release spikes and the time between the release of the articulators and the onset of regular voicing is labelled ‘H’. The sound pressure waveform provides the information about the exact positioning onset of the release spike and in combination with the spectrogram it is possible to mark the end of the aspiration/VOT period. When no release burst is found the aspiration/release portion was not labelled. Velar lenis stops in particular are typically realised as fully voiced approximants [u]. This weakening process is discussed in more detail in the previous chapter and within the experiments. The transitions in and out of the consonant from the vowel are also marked as either ‘t1’ or ‘t2’. In the example in Figure 5.1 the voicing portion of the stop continues across the entire length of the consonant. This period of glottal

vibration is labelled 'V'. Occasionally the voicing ceases before the release of the articulators and in this case a negative symbol '–' is used to indicate cessation of voicing.

Figure 5.2 shows the labelling criteria used for fortis stops. The word *kabbal* 'flood plain' shows a short period of voicing which extends into the stop after the onset of closure. This is the VTT and is marked with 'V' on the *Qualitative* tier. The voicing fully ceases for a significant portion of the consonant and this is marked with a negative symbol '–' to indicate an absence of glottal pulsing. As in lenis stops, the VOT period is labelled as 'H'. This marks the time between the release of the articulators—indicated by a release spike—and the onset of regular voicing, after which the signal is labelled as a vowel with a transition marker 't1' on the *Qualitative* tier. These are the major landmarks labelled for the durational analysis. See the aerodynamic labelling below for further information on the segmentation labelling of the multichannel data.

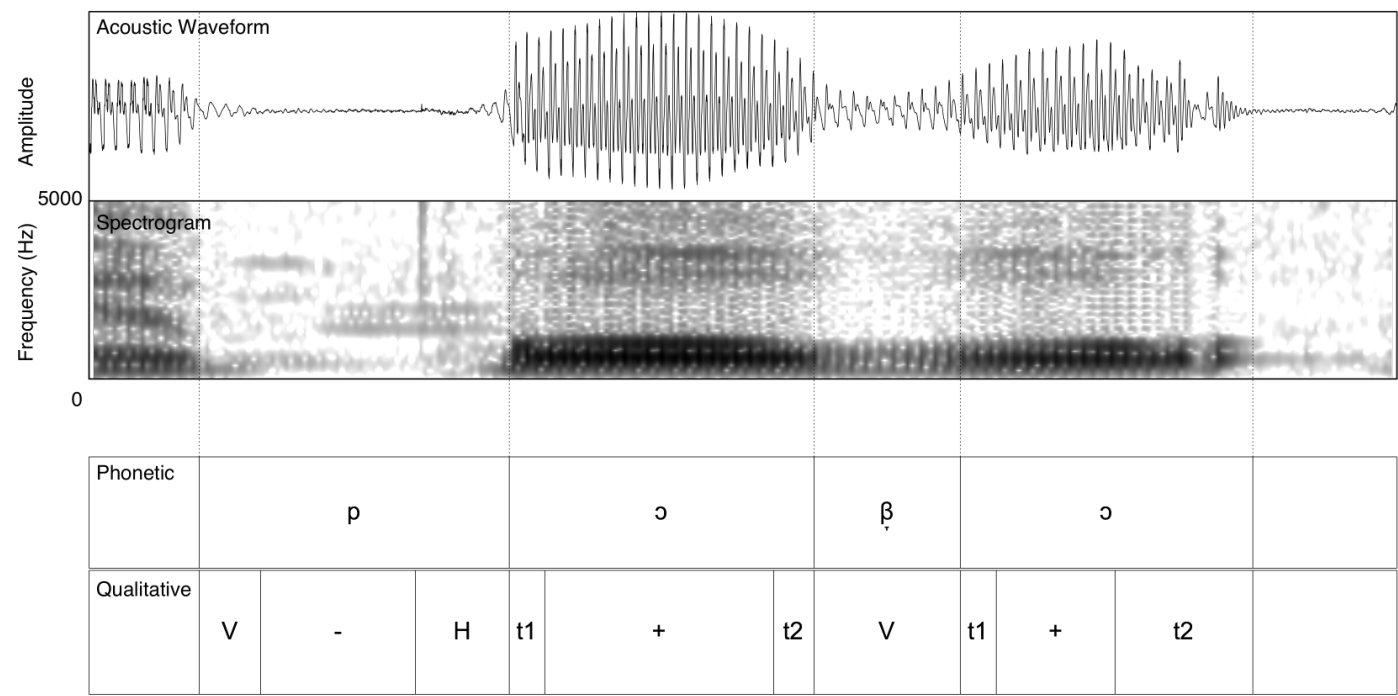


FIGURE 5.1: Measurement criteria for medial voiced stops showing a medial bilabial lenis stop (realised as an approximant) [β] within the word bobo, ‘goodbye’.

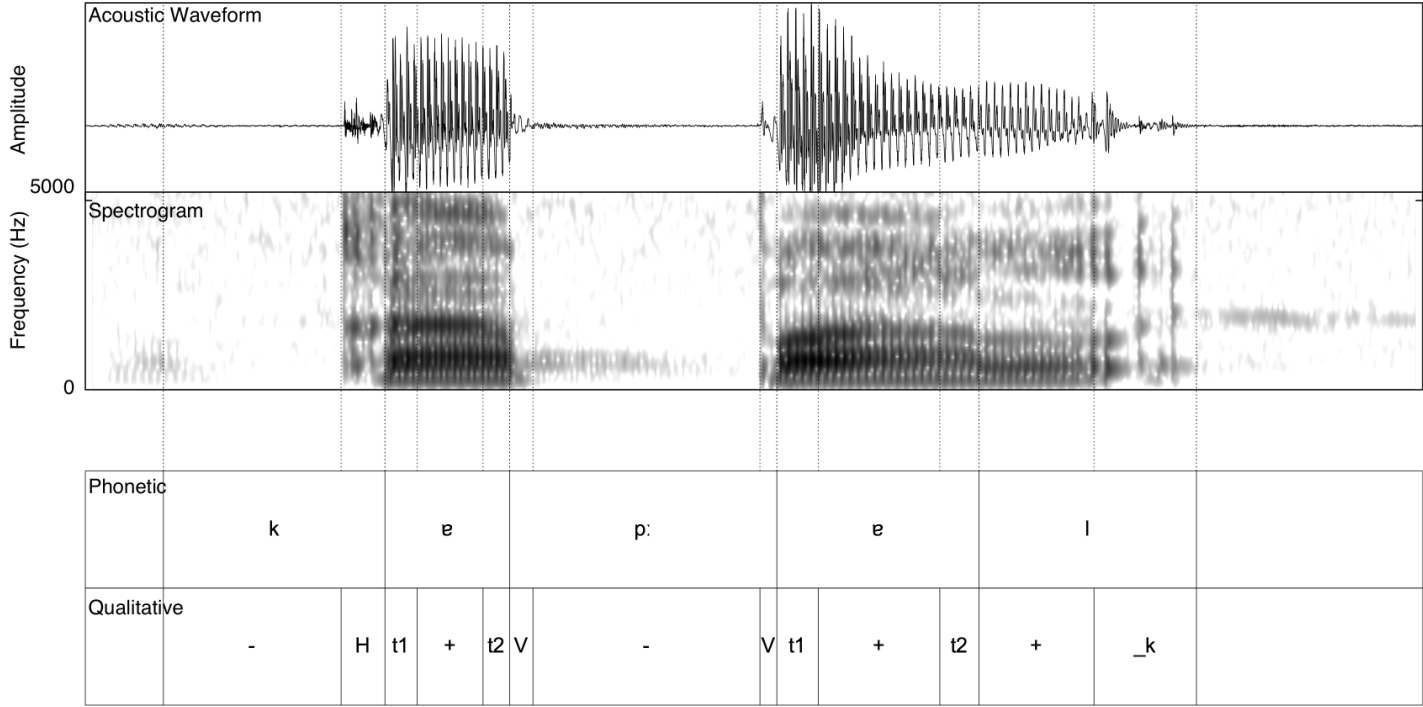


FIGURE 5.2: Measurement criteria for medial devoiced stops showing a medial bilabial fortis stop [p:] within the word kabbal, ‘floodplain’.

5.5 Statistics

All data were analysed within the *R* statistical environment (R Core Team, 2014). The database of sound files and time-aligned physiological signals and hierarchical label files was managed within The Emu Speech Database. The statistical analysis was completed using the *R* packages *lme4* (Bates, Maechler, & Bolker, 2011) and *languageR* (Baayen, 2008; Baayen, Davidson, & Bates, 2008; Baayen, 2011). Visualisation was performed using the *ggplot2* package (Wickham, 2009) which is an implementation of Wilkinson's (2005) *The Grammar of Graphics* within the *R* environment.

5.5.1 Linear mixed effects models

The data were analysed using general linear mixed effects models (LMEM) in favour of ordinary regression analysis and an analysis of variance (ANOVA).

An ordinary regression is summarised as:

$$Y_i = \beta + \beta_1 X_1 + (e_i), \quad (5.2)$$

where the error term is e_i , and X is the fixed effect. However, a regression is not sufficient when estimating coefficients from a sample of repeat observations. This is because a linear regression assumes all observations are independent and uncorrelated. For this reason linear mixed effects models have been used in this study. A LMEM can be summarised as:

$$Y_{ij} = \gamma_0 + \gamma_1 X_1 + (u_{0j} + e_{ij}), \quad (5.3)$$

where i indicates the observations (the tokens in this study) and j indicates the participants (speakers). This model includes random effects u_{0j} as well as fixed effects X (Quené & Van den Bergh, 2008). This enables the fitting of mixed-effects models with crossed random effects (Bates, 2005).

All data were examined visually to look for normality and homoscedasticity using residuals plots against fitted values. This utilises functions within the

lme4 package (Bates et al., 2011) and the base *R* environment. In order to check the validity of the mixed effects analyses a likelihood ratio test must be performed which compares two analyses of variance (anova), one that includes the fixed effects compared with the null model that includes only the random effects. The outcome of these tests is reported as Chi squared (χ^2) according to Wilk's Theorem (see Wilks, 1938, Williams & Williams, 2001, p. 377 and Winter, 2013). If the model including the fixed effects has results that do not differ significantly from the null hypothesis the entire model is rejected. Throughout this thesis measurements of statistical significance are reported as Chi squared (χ^2) with post hoc Tukey Honest Significant Difference (HSD) tests resulting in reported p-values that are considered significant at the $\alpha=0.001$ level (although it should be noted that an $\alpha=0.01$ was not rejected). The language-as-a-fixed-effect fallacy—as noted by Clark (1973)—was avoided by including both *Speakers* and *Tokens* as random effects (see Baayen et al., 2008). Main effects were tested and additional interactions were investigated.

5.6 The method for the acoustic experiment

When looking for a reliable indicator of a phonetic difference between two oral stop series, duration is often the only reliable difference found (see 2.2). This durational difference is found regardless of whether they are described as geminates and singletons, long and short, fortis and lenis or tense and lax (see § 2.1.2 and § 4.1 for a survey of experimental research regarding these phonological labels).

The labels within The Emu Speech Database are organised into a hierarchy. In order to report the variation found within the phonological categories data are labelled with both an orthographic tier (labelled *emic* in Figure 5.3) and a phonetic representational tier (labelled *etic* in Figure 5.3). The orthographic tier is equivalent to the phonological analysis. The *phonetic* tier has been hand

labelled using acoustic landmarks (see Figure 5.4 on page 125). The *phonemic* tier is derived from the orthographic word list and where there are inconsistencies between the two tiers—for example due to speech error or orthographic transcription error—they have been resolved using a *broad* tier that attempts to co-ordinate the etic and the emic. This is necessary due to the size and nature of the corpora.

Each phonological label has a number of associated allophones (see § 5.4.1 for further information). In addition to the allophonic variation there are coarticulatory effects that—albeit rarely in citation form—can cause the elision or epenthesis of segments in certain environments. These will be discussed if relevant to the analysis. Orthographically the lenis stops are labelled using a single grapheme—for example ⟨k⟩ for a velar lenis stop—whereas a fortis stop uses a doubled grapheme (e.g. ⟨kk⟩).³ The orthography for Kunwinjku is used exclusively in this study to avoid confusion with the orthographic systems of other Bininj Gun-wok varieties. The phonological labels are, in the main, congruent with the orthographic representation of Bininj Gun-wok words, however, the allophonic variation associated with different voicing values is not encoded in the orthography. Where possible the analysis below is formulated using the phonetic label in an effort to remain unbiased by any orthographic ambiguity. This is most important in the analysis of medial stop clusters, and homorganic clusters in particular, as they are orthographically indistinguishable from fortis stops. In the Orthography both homorganic clusters and fortis stops have sequences of two identical graphemes meaning they cannot be reliably differentiated lexically without a morphological awareness of the language. The phonetic analysis of voicing, and further spectral analysis is based on the phonetic labelling derived directly from the analysis of both the spectrogram and the speech waveform (sound pressure waveform) of the utterance. The criteria

³The orthographic conventions used for the various dialects of Bininj Gun-wok are summarised in the Table A.1 in the Appendix A.8.

for landmark identification and labelling are detailed in § 5.4.2.

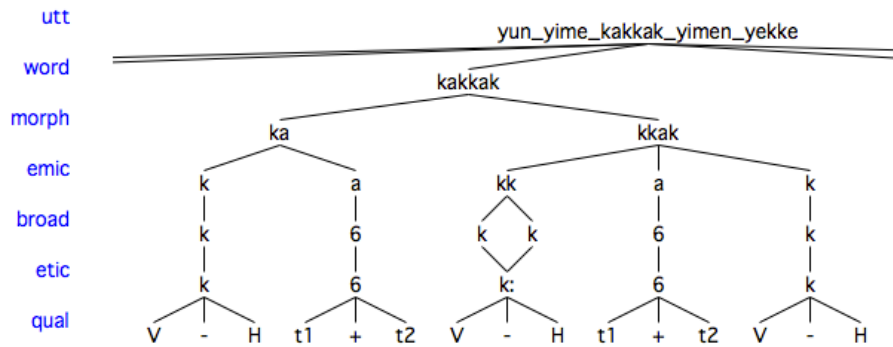


FIGURE 5.3: An example of the hierarchy within the Emu Speech Database.

The measurements of medial consonant duration are based on total medial consonant duration (see § 5.6.3). This is done primarily in order to directly compare these results with earlier work on Australian languages. As noted in the methodology and literature review of experimental studies in Australian languages, there are a number of techniques that can be used to determine the onset of the stop and its release. This study uses the offset of high frequency energy (> 500 Hz) in the vowel (shown at 1 in Figure 5.4) as the main criterion for labelling the onset of the consonant, the burst as the point of release (a transient in the speech wave form and broad spectrum frequency excitation, shown at 2) and then the onset of regular voicing, measured as the start of the first complete glottal pulse as the offset of the consonant and the onset of the following vowel (shown at 3).

5.6.1 Materials

The total sample used in this study consists of 2461 tokens, of which 1316 tokens contain medial fortis stops and 1145 tokens contain medial lenis stops. The total sample combines recordings from both Corpus I and Corpus II for the duration experiments, unless explicitly stated. This sample forms the basis of

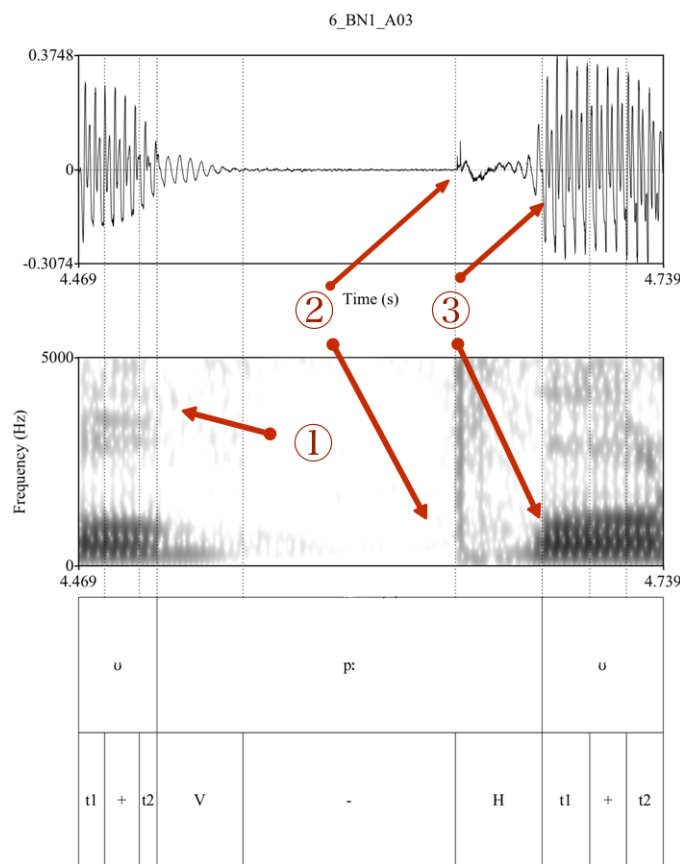


FIGURE 5.4: Labelling of the onset (1), burst (2) and offset (3) within a medial fortis consonant [p:].

the analysis. Corpus I contains 1216 tokens (472 fortis and 744 lenis)⁴ and Corpus II contains 1245 tokens (844 fortis and 401 lenis). There are 70 unique words found in the data set (see Appendix B.2).

The acoustic recordings in Corpus II are better suited to analysis of low amplitude acoustic events, for example, the incidence of voicing after closure or release burst structure. These recordings have a relatively high signal-to-noise ratio when compared to the acoustic recordings that are part of Corpus I. The lexical items that comprise Corpus II focus on words that exemplify aerody-

⁴This is a subset of the 2658 words in total from Corpus I

namic differences and in addition those that possibly control for the difference between intra-morphemic and inter-morphemic long stops. Due to the limitations inherent in aerodynamic recordings discussed in the method (§ 5.7.1), there are a greater number of tokens in the peripheral class (bilabial and velar) compared with the coronal class (apico-alveolar, retroflex and lamino-palatal). In Corpus II, the coronal places of articulation are underrepresented for multiple repetitions for the majority of speakers. It is primarily for this reason that data from Corpus I are included in the analysis.

When measuring VTT and VOT, tokens from Corpus II were favoured. There is less ambient background noise in the recordings for Corpus II largely due to favourable field conditions. A total of eleven speakers are used in the analysis of VOT found in § 6.5.1. Five speakers from Corpus I and six speakers from Corpus II are included, but due to the relative small number of tokens recorded for coronals, the recordings of only three speakers were used for the measurements at the palatal, alveolar, and retroflex (apico-postalveolar) places of articulation. The F_0 and spectral analyses utilise data from both Corpus I and Corpus II. When data is pooled from both corpora, corpus membership is included as a random factor when calculating linear mixed effects models. In general each corpus is kept separate during the analysis.

Each word in Corpus I has three repetitions per speaker. The measurements are restricted to tokens in the second repetition. For Corpus II, due to the relatively small sample size for stops at some places of articulation, it has been necessary to use tokens from both the first and second position in the carrier phrase.⁵

⁵This is particularly true of the post-alveolar/retroflex place of articulation and for some of the male speakers who only produced a subset of the wordlist or did not complete the entire list.

5.6.2 Queries

The two corpora are combined into a single database for the durational analysis and kept separate dependent on the research questions and hypotheses tested. Complex querying of the resulting databases are passed to the *R* software via The Emu Speech Database, allowing data visualisation and high level statistical analysis. Once the labels are integrated into the analysis it is possible to query the entire speech corpus and extract any segment in a parent or child tier for any given segment or string of segments. This analysis can also be performed sequentially along the same tier or alternatively on a different tier. Additional information regarding possible queries within The Emu Speech Database, can be found in *Phonetic Analysis of Speech Corpora* (Harrington, 2010). This powerful querying language was essential for isolating the segments and sequences central to the current study—namely medial structures.

5.6.3 Measuring consonant duration

The acoustic duration experiments consist of various measurements utilising particular acoustic landmarks within the stop. Total consonant duration is the time measured from the point of oral closure, indicated by reduced high frequency activity on a spectrogram, until the onset of regular voicing. This measurement includes the VOT and also any VTT in the calculations. All duration measurements in Chapter 5 are based on labelling of the landmarks within the acoustic signals rather than quantitative analysis of the articulatory records, although articulatory data have informed the choices made in labelling.

5.6.4 Voice onset time

The measurement of voice onset time (VOT) (see § 2.3) uses the labelling described in § 5.4.2, to define the references to the speech signal. VOT can be formally stated as:

$$VOT = T_{onset} - T_{release},$$

where T_{onset} is the time of the onset of regular voicing in the following vowel and $T_{release}$ is the moment of the burst which is taken to be the release of the articulators. VOT differences are dependent on the place of articulation and as mentioned in § 2.3, it has been established that the further back the closure in the oral cavity the longer the VOT (Byrd, 1993; Maddieson, 1999a). This is assumed mainly to be due to the size of the resonant cavity behind the closure. Consequently velars usually have a longer VOT than bilabials. Also the more extended the contact area, the longer the VOT, which in Biniŋ Gun-wok includes palatals with large areas of tongue contact with the pre-palatal area.

Related to area of contact is the speed of the articulator. The faster the articulator can move, the shorter the VOT due to less articulatory constraint. In Biniŋ Gun-wok the retroflex (post alveolar) and the apical places of articulation both use the tip of the tongue as the primary articulator which, due to its high mobility, is a fast articulator. Consequently, it is predicted that the VOT will be relatively short at this POA. These hypotheses are investigated and the associated VOT measurements for both medial and initial stops. The results reported in § 6.5.1 come from both Corpus I and Corpus II, although where possible, Corpus II is used due to the favourable signal-to-noise ratio of the recordings making the identification of weak bursts easier.

5.6.5 Voice termination time

Voice Termination Time (VTT), is the time between the onset of a stop (offset of the vowel) and the offset of periodic voicing.

It is well known that obstruents with a long duration or geminated consonants are more likely to be voiceless due to the difficulty in maintaining voicing when there is an associated increase in intra-oral air pressure (Ohala & Risor, 1979; Westbury, 1983). As discussed above in § 2.4.2 on page 54, after a voiced segment, such as a vowel, vocal fold vibration may continue for up to 100 ms after oral closure. This is particularly true if the rest position of the

vocal folds remain in an adducted position allowing for passive voicing. There is a limit however as to how long voicing can be prolonged in stop closure as the trans-glottal pressure differential must be maintained.

There are a number of possibilities for the realisation of VTT:

1. The stop is actively voiced for the entire closure resulting in a fully voiced stop.
2. The stop is passively voiced for the entire closure resulting in a partially devoiced stop.
3. The stop is passively devoiced resulting in a voiceless stop.
4. The stop is actively devoiced resulting in an abrupt VTT and a voiceless stop.

It has been proposed that VTT can be used as an alternative, or in addition to VOT as a cue to the phonological category [$\pm$ tense] (cf. Steriade 1997; Helgason 1999). See also, § 6.5 for frequency count of the different stop realisation types within the corpora.

Due to the low amplitudes of VTT into the stop closure, only recordings with an acceptable signal to noise ratio are included within the analysis. This criterion means only recordings from Corpus II are used in measurements of VTT in the analysis detailed in § 6.5.

5.6.6 Vowel duration and vowel to consonant ratio

In many languages cues to duration and voicing in stops are not restricted to the segment itself. Measurement of vowels preceding fortis and lenis stops have shown that vowels preceding fortis stops are considerably shorter than vowels that precede lenis stops. This vowel length effect has been termed pre-fortis clipping in English (Wells, 1990). As noted above in § 4.1.2, this vowel difference was not found in Jarwoyn (Evans & Merlan, 2004).

Vowel lengthening before voiceless stops has been shown to be a cue to differentiating between stop classes in many languages (Port & Dalby, 1982). In addition to this, the ratio between the vowel duration and the consonant has been shown to correlate with fortis stops (Kohler, 1984). Debrock (1977, p. 61) says that pre-consonantal vowel duration is generally accepted as a distinction between lenis and fortis consonants and can indicate differences in ‘force of articulation’. In order to determine physiological differences between stop types, Debrock (1977) measured the rise and decay times of the amplitude of vowels surrounding lenis and fortis consonants. Delattre (1971b) did not find an association between the duration of the preceding vowel and the ability to distinguish a geminate consonant from a singleton in a study of four languages (English, German, Spanish and French).

There is an association for Italian geminates and singletons (Smith, 1995) and for a number of other languages, as discussed in Chapter 2). In Malayalam, Local and Simpson (1999) measured vowel to consonant duration for each vowel surrounding intervocalic geminates and non-geminates and found that both vowels preceding and following ‘long nouns’ (words containing intervocalic geminates) show a smaller consonant:vowel ratio than vowels preceding ‘short nouns’ (words containing intervocalic non-geminates).

In the current study the association between vowels preceding (V_1) and vowels following (V_2) fortis and lenis stops in Bininj Gun-wok are investigated. The C/V ratio is the ratio of closure duration and the duration of the preceding vowel. This ratio can be stated formally as:

$$(C/V)ratio = \frac{T_C}{T_{V_1}},$$

in a V_1C_1 syllable rhyme, where T_C is the closure duration (total duration less the duration of VOT) and T_{V_1} is the duration of the preceding vowel in milliseconds. Similarly the ratio of consonant to following vowel is the same as the equation above substituting T_{V_2} for T_{V_1} .

5.6.7 Analysis of burst amplitude

Relative amplitude of the burst in lenis and fortis stops has shown to be a reliable indicator of differences between stop category in languages, for example, Local and Simpson (1999) for Malayalam, Hamzah, Fletcher, and Hajek (2012) in Kalantan Malay and Doty et al. (2007) for Finnish. This may be as a result of differences in respiratory or articulatory effort. The relative amplitudes of the burst has been shown to differentiate stop types in some languages but not for others. An analysis of amplitude is conducted using the average Root Mean Square (RMS) amplitude of the acoustic signal with time window centred on the bursts.

$$\Delta_{amp} = Amp_{burst} - Amp_{vowel},$$

where Amp_{burst} is the RMS amplitude 5 ms after the burst and Amp_{vowel} is the mean RMS amplitude of the following vowel both measured in dB. This is a similar measurement to that used by DiCanio (2012).

5.6.8 Spectral analysis

Previous studies on differentiating between consonant types have shown that the burst spectra at the offset of closure is no better than formant transitions in predicting stop type (Dorman, Studdert-Kennedy, & Raphael, 1977). A more consistently reliable method for the analysis of stop type uses the locus equation metric (see § 3.2.3). For the spectral analysis of bursts the analysis uses a Blackman window Discrete Fourier Transform (DFT) with 2048 points with a linear prediction spectrum (LPS) overlay.

5.6.9 Locus equations

It is possible to calculate the coarticulatory effects in vowel to consonant formant transitions which have shown to differentiate different places of articulation (see § 3.2.3). Lindblom et al. (2007) examined the effects of emphatic

stress on consonant to vowel coarticulation. Results showed, however, that vowel expansion was more important than the effect of the consonant. The current study looks at both vowel to consonant and consonant to vowel transitions in a VCV phoneme sequence using the second formant (F_2).

Two measurements are reported for V_1CV_2 sequences. In the first, the second formant (F_2) is measured at the vowel target (very close to the vowel midpoint) of V_1 and then again at the offset of the consonant. In the second the second formant (F_2) is measured at onset of the consonant and at the vowel target of V_2 . Each of these measurements are then correlated and a linear regression line is calculated using the following equation:

$$L = c/(1-\alpha),$$

where L is the locus frequency and c and α are the intercept and slope of the locus equation respectively (Harrington, 2010). This is a measurement of linear regression and a fitted line is plotted against a line with a slope equal to 1. The degree of anticipatory coarticulation can be derived from the slope values of this fitted regression line. A high slope value indicates that there is a high degree of anticipatory co-articulation and a low slope value shows that a consonant is resistant to anticipatory co-articulation.

Figure 5.5 shows a hypothetical V_1C_1 sequence with F_2 measured at the midpoint of the vowel and at the offset of the vowel, just prior to the onset of the consonant (C_1) (see Figure 5.6). V_1 is measured at the midpoint and the offset and V_2 is measured at the onset and the midpoint. In some instances the terms C_1 onset and also C_1 offset are used but it is important to note that the measurements of F_2 are all made within the vowel. The measurements are all proportional measurements, with the V_1 midpoint at precisely 50% and the V_1 offset at 95% of the vowel duration. V_2 onset at 5% into the following vowel. In Figure 5.5 dotted line shows a slope of 1 which would indicate the F_2 at the midpoint of the vowel was the same as the F_2 at the offset or onset of the vowel

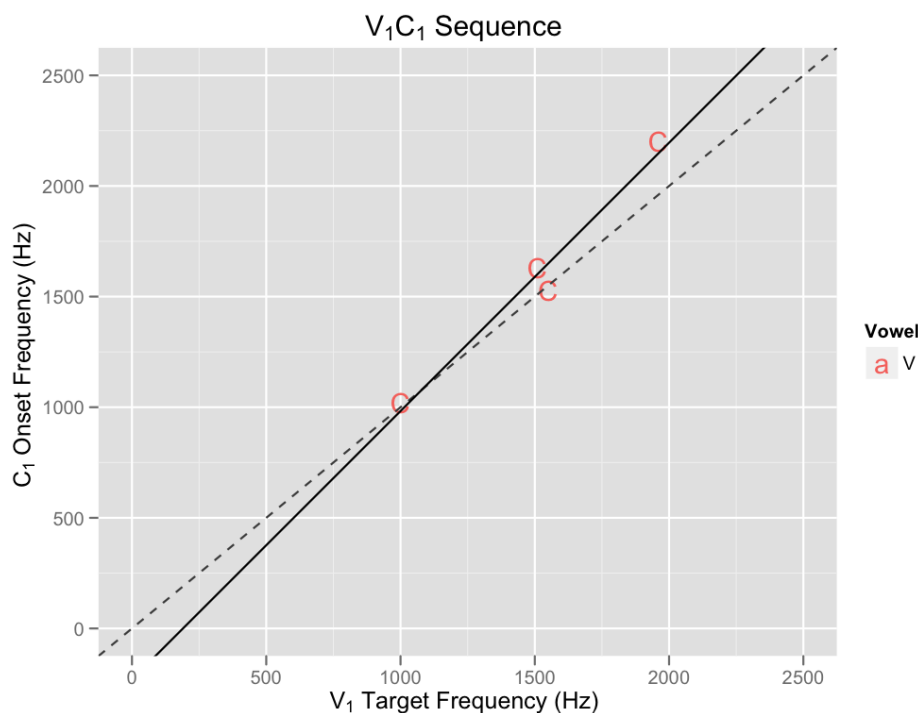


FIGURE 5.5: The locus equation plot for a hypothetical VC sequence.

and that the vowel there was no assimilation exerted by the following segment. The black line shows a fitted regression line and a slope that approaches 0 would indicate that the following segment exerts more influence over the preceding segment (as discussed above in § 3.2.3). Due to the phonotactics of Bininj Gunwok it is assumed that there will be a syllable boundary between either the V\$C or between C\$V and this factor is not controlled within the study (see § 1.3.2).

The F_2 locus has shown to be a good descriptor for place of articulation particularly for alveolars and bilabials. It does not adequately differentiate between the coronals however (see § 3.2.3). This limitation is an issue for studies in Australian languages which have comparatively high number of coronal distinctions. Locus equations are able to measure levels of coarticulation between adjacent segments and do tell us something about the inherent coarticulation

5.7 The method for the physiological experiments

The aerodynamic analysis of speech is highly reliant on the acoustic signal. Changes in air flow and pressure can be correlated with associated changes in the acoustics. This can signal the timing of the articulators and from these changes in air-flow patterns it is possible to infer articulator movement. This can be the primary oral articulators in the case of oral stops and nasals or movements of the velum in nasals. Multi-channelled data is ideal for the analysis of aerodynamics as interpretation of a single signal can be ambiguous. Just as the acoustics of speech are a complex structure comprising many signals the aerodynamics must also be considered as a gestalt.

5.7.1 Aerodynamic recordings

The multichannel articulatory recordings were made via a *Scicon R&D* airflow mask with an inbuilt microphone and transducers connected to a *Scicon R&D 916* capture device (*Scicon R&D California, USA*) which in turn was attached to a *Dell Latitude D510* laptop running *Microsoft Windows XP Professional (Service Pack 2)* (see § 5.7). The system was controlled using *PCQuirer* software (Version 7, *Scicon R&D California, USA*).

Volume velocity of the airflow from the mouth (U_o) and nose (U_n) is registered by means of a pneumotachograph (an apparatus used to register the rate of airflow to and from the lungs). The method used in this study is very similar to that of Yanagihara and Hyde (1966) in their study of bilabial stops. Oral and nasal airflow was recorded via separate masks with speaker holding a mask over the mouth and a separate mask attached to the nose by means of a strap around the head. This eliminates the risk of leakage between chambers, which is possible if the measurements were made using a single partitioned mask (see Figure 5.9 on page 140). Within each mask the pressure drop across a nylon gauze is registered by a variable reluctance differential pressure trans-

ducer connected to the outside of the oral airflow mask via plastic tubing (5 mm inner diameter), similar to that used by Butcher (1992). A microphone is also mounted in the oral mask to record the audio signal from the mouth. This signal (either 11 or 22 kHz⁶) had marked attenuation of higher frequencies and consequently is used only as an aid to subsequent segmentation of the synchronous airflow signals. These audio signals are of sufficient quality for the labelling of acoustic landmarks and the measurement of durations, including closure duration, VOT and VTT. Intra-oral pressure is measured during bilabial articulations by asking the speaker to speak with a 2 mm (inner diameter) plastic catheter placed between the lips (as per Butcher, 1992).

No pressure measurements from other the places of articulation were possible as any recording of intra-oral pressure in non-coronal articulations involving the the tongue dorsum (e.g. palatal or velar) require the insertion of a flexible plastic tube through the nose and into the pharynx.⁷ Some apico-alveolar measurements of intra-oral pressure were possible for some speakers but unfortunately there were insufficient data for inclusion in the quantitative analysis.

The device is calibrated for oral flow, nasal flow and oral pressure using the *CAL 220* device developed by *Scicon R&D*. The airflow transducers were calibrated by placing the masks onto the Perspex cylinder of a *Scicon* calibration device (*Scicon R&D CAL220*). Air is allowed to flow into the mask at a known rate. This is done at 8 set rates (0, 5, 10, 15, 20, 25, 30 and 35 l/min⁸) recorded at an arbitrary gain of 5 units. This calibration followed the method described in Ladefoged (2003).

Calibration for all devices was completed before commencing fieldwork and then again upon return at the Phonetics Laboratory of The University of Mel-

⁶Note that this is not the standard 11.025 kHz or 22.5 kHz usually used in sound recording.

⁷see Ladefoged (2003, pp 57-8), for more information regarding the disadvantages of taking velar pressure measurements.

⁸See Appendix A.6 for unit conversions for pressure and flow.

bourne. There was a high degree of consistency between the calibration sessions with only the zero level needing re-calibration after transport. The pressure transducer was calibrated at the Phonetics Laboratory of The University of Melbourne using the 'u-tube manometer method' detailed in Ladefoged (2003, p. 63) and Baken and Orlikoff (2000, p. 298), and then re-calibrated in the field, using a ruler and a glass of water. Re-calibration of the pressure transducers is essential once at the field location as there are changes in pressure and ambient temperature associated with differences in altitude and climatic conditions. The volume velocity of flow is measured in Litres per minute (l/min) and then converted to millilitres per second (ml/s or the equivalent SI unit $\text{cm}^3 \text{s}^{-1}$).

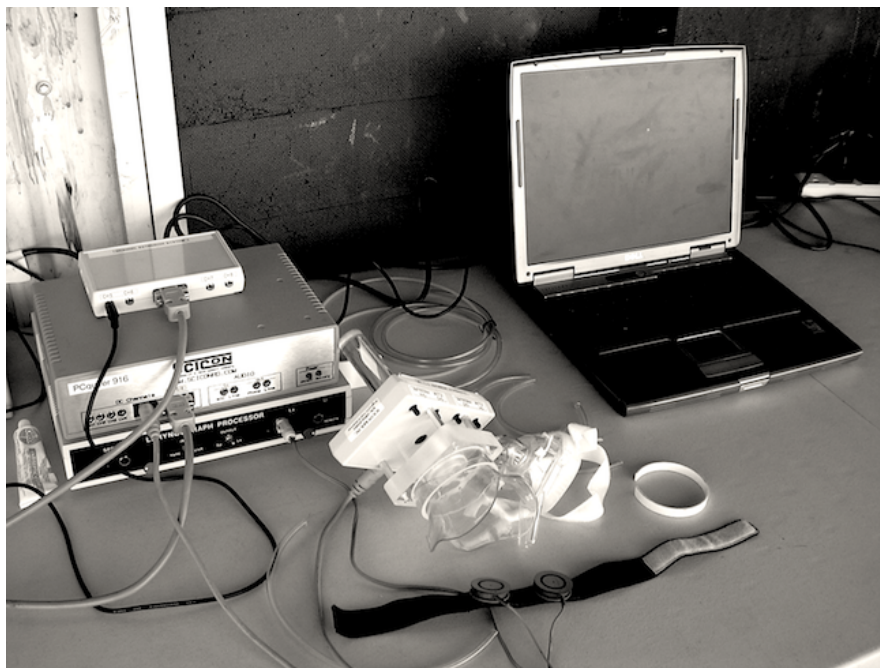


FIGURE 5.7: *The aerodynamic recording workstation at the field location.*

In figure 5.8 (the raw multichannel output from *PCQuirer*) the baseline represents atmospheric pressure; thus any trace above the baseline represents pressure within the mouth greater than atmospheric, and a trace below the line (where it occurs) represents pressure less than atmospheric. Similarly egres-

sive airflow is indicated by a trace above the baseline and ingressive flow by a trace below the baseline (see § 5.8). The calibration method for the pressure transducers uses centimetres of H₂O (cm H₂O) as the base unit of measurement. The SI unit of pressure is the Pascal (Pa) and consequently the conversion rate of 1 cm H₂O = 98.0392 Pa, or conversely, 100 Pa = 1.02 cm H₂O, was applied.⁹

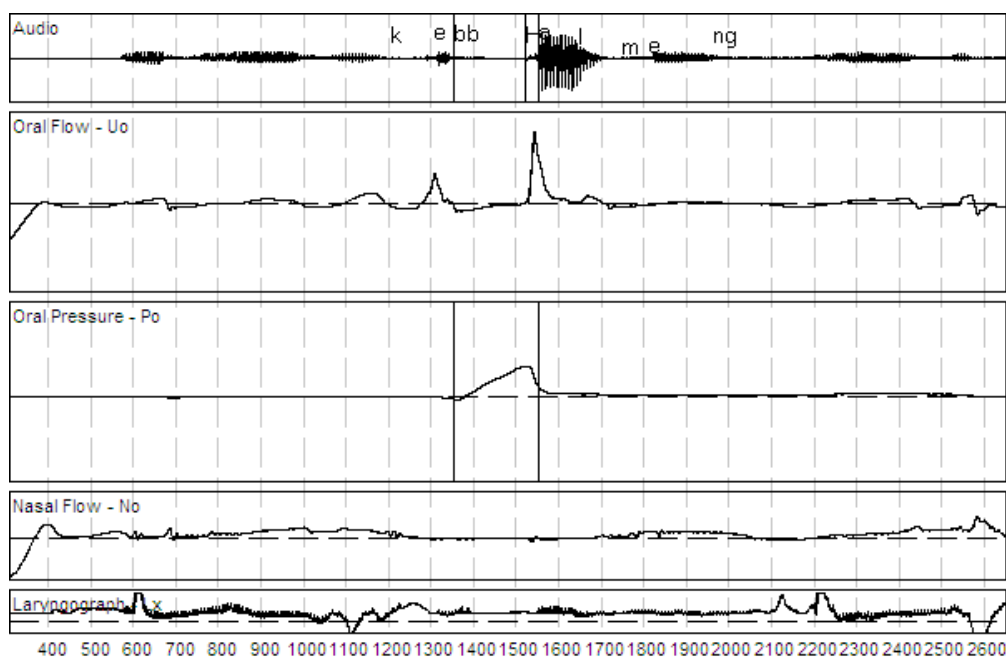


FIGURE 5.8: A record of the Kunwinjku word kebbalhmeng ‘to close your nose’ with in a carrier phrase, taken from PCQuirerX showing oral flow (U_o), oral pressure (P_o), nasal flow (marked here as N_o but elsewhere U_n) and Laryngograph traces (L_x).

There are a number of disadvantages associated with the pneumotachograph device identified by Anthony and Hewlett (1997). Firstly, air leakage even in systems with separate masks is a constant problem. Due to the *Scicon* mask design, in this study for some speakers the lower portion of the nasal mask did not make a comfortable sealed closure. Along the cheeks, when articulating high vowels, there was also an increased chance of leakage in both

⁹This conversion rate has been incorrectly quoted by Baken and Orlikoff (2000, pp 315–16, 330) as “1 cm H₂O = 10.2 kPa” (sic) but this is the inverse of the correct values, inflated by a factor of 10.

the nasal and oral masks. Consequently, during the experiment the mask was refitted after the recording of each token, significantly adding to the recording time. In the course of long recording sessions consultants can become fatigued and relax the air seal very slightly but enough to make the measurement uncalibrated and consequently unusable. Another less serious disadvantage of this technique comes from the resistance at the flow-head. Ideally the flow head would have no resistance at all, allowing for clear unimpeded speech. This is not the case as there is an inherent resistance in the system that is dependent upon the design and materials used in the mask and flow-head. Anthony and Hewlett (1997) describe the resistance associated with the “Type F2 (19 mm bore) manufactured by Mercury Electronics (Scotland) Ltd”.

Using a model of the aerodynamic system in which speech mechanisms (physical, physiological and acoustic) are described in terms of an electrical circuit analogue (c.f. Rothenberg, 1968), the expiratory resistance of the respiratory tract was measured. Rothenberg (1968) refers to an ‘electrical circuit analog’ that models the aerodynamic system involved with speech onto voltages and resistances. This is developed from the electromechano-acoustical dynamic systems introduced by Beranek (1996). Similar models based on this analogy have been used by Müller and Brown (1980) and Westbury and Keating (1986). Stevens (1998, p. 3) also uses an electrical circuit schematisation for representing the mechano-aerodynamic system. In each of these models, airflow is represented by a voltage (V). An Ohm (Ω)—the standard measure of electrical resistance—is used to represent the resistance applied to the rate of flow is analogous to the physical impedance to flow (cm H₂O/l/s):

$$1 \Omega = \frac{1 \text{ cm H}_2\text{O}}{1 \text{ L/s}}$$

The resistance of the vocal tract varies from 0.5 Ω for open vowels (i.e. almost no resistance) to 100 Ω at least in fricatives. The resistance of the transducer and flow head of the previously mentioned F2 mask are estimated as having

the nominal resistance of 1Ω which is approximately equivalent to reducing the flow by $1 \text{ cm H}_2\text{O/l/s}$. This level of resistance is not thought to be noticeable to a speaker wearing the mask for either breathing or normal speech. The *Scicon* mask used in this study is assumed to have similar resistance characteristics to those previously rated, with a low overall flow-resistance when compared with that of the vocal tract.



FIGURE 5.9: A participant wearing the oral and nasal masks demonstrating the experimental configuration.

5.7.2 Disadvantages with aerodynamic techniques

It is not possible to gather synchronous high quality acoustic recordings along with the aerodynamics as the oral mask causes acoustic interference. The *Scicon* mask has the microphone placed at the end of the mask (on the outer side of the gauze flow-head) to record audio data that is synchronised with the aerodynamic records. The audio quality, however, is significantly degraded mainly due to the split in the oral and nasal outflows. This results in some loss of high

frequency information spectral and difficulty in the observation of nasal murmur from the acoustic channel. The resulting audio recordings are still acceptable for broad phonetic segmentation however, and can be used for durational measurements of both vowels and consonants. The oral flow mask blocks many higher sound frequencies associated with speech in a similar manner to speech transmitted via a standard wired telephone (Lawrence, Nolan, & McDougall, 2008). Frequencies above 5000 Hz are attenuated and there is also some low frequency loss observable. In general the other frequencies are relatively unaffected. It should be noted though that Badin *et al.* (1990) cited in Gick, Wilson, and Derrick (2012, p. 66) say amplitudes above 1000 Hz are distorted, and this is in the range that would affect the second formant frequencies (F_2). Due to this limitation, it is not possible to use the aerodynamic data in the acoustic analysis of formant frequencies or spectra. The exception to this is the voice analysis which correlates speech spectrum data with articulatory data. In this case the formants were checked visually for accuracy where possible.

5.7.3 Data processing and analysis

Prior to analysis of these aerodynamic data, some technical considerations needed to be addressed. The aerodynamic data recorded in the second field season (in 2006) were collected without means of signal filtering during the recording stage. This necessitated *post hoc* filtering to be applied to the aerodynamic recordings. Filtering of aerodynamic records enables low frequency signals that are masked by higher frequency signals to be removed. The higher frequency component primarily represents voicing and this must be removed in order to view and analyse the data. All the aerodynamic records gathered comprise high frequency and low frequency components. It is the low frequency component of the aerodynamic record that contains the required flow information needed for further analysis. In speakers that have relatively low overall airflow such as those recorded in the current study, the glottal source compo-

ment, which is of a overall higher frequency, can mask the lower frequencies that are an indication of the rate of flow. It is thus necessary to use a low pass filtering with a cut-off frequency ranging between 40 Hz to 60 Hz (depending on the sex of the speaker, with males requiring a lower cut-off filter). As noted above, the transducers that record pressure and flow are very sensitive and thus prone to lose zero calibration after transport due to changes in temperature and ambient pressure. Unfortunately the zero offset was not apparent in the unfiltered records which necessitated the application of an offset factor subsequent to filtering thus enabling accurate data measurements to be made. This was done using with a high-pass-filter with a very low frequency threshold in order to remove the DC-offset and leave the AC signal unaffected. Consequently each of the records was exported and filtered separately. This enabled importing of the synchronous audio and articulatory channels into the EMU speech database.

Recording speech data via multiple channels enables the return of a great variety of information. Oral flow (U_o), oral pressure (P_o), nasal flow (U_n), and glottal activity (L_x and G_x) were recorded, extracted and input into the Emu Speech Database. Once imported they were segmented and labelled using both the EMU labeller and Praat. The EMU Speech database has at its core, a hierarchical structure (Harrington, Cassidy, Fletcher, & McVeigh, 1993). The labels that correspond to the audio file are arranged into tiers with a parent/child relationship (Cassidy & Harrington, 2001). This structure enables complex hierarchical querying of the database with dependencies spanning over multiple tiers (Harrington, 2010, p. 77). These hierarchical queries were essential for isolating the medial phones from phones in initial or final environments. This could further be restricted to the word or syllable level.

5.7.4 Channel processing

The aerodynamic recordings were recorded as PMF files which can be read by PCQuirer. The individual tracks can be exported as wave (WAV) files the as-

sociated header information for each tracks is shown in Tables 5.5 and 5.6.¹⁰ The channels recorded and the subsequent filtering of the signals is summarised below. To enable accurate analysis a number of processing and filtering techniques were applied to the raw data from each channel.

TABLE 5.5: *Formats for Aerodynamic Recordings, field season 2.*

TRACK	CHANNEL	FORMAT	SAMPLE RATE
WAV	Audio Channel	Little Endian headerless WAV file	11 kHz
U_o	Channel 1	Little Endian headerless WAV file	11 kHz
P_o	Channel 2	Little Endian headerless WAV file	11 kHz
U_n	Channel 3	Little Endian headerless WAV file	11 kHz
L_x	Channel 5	Little Endian headerless WAV file	11 kHz

TABLE 5.6: *Formats for Aerodynamic Recordings, field season 3.*

TRACK	CHANNEL	FORMAT	SAMPLE RATE
WAV	Audio Channel	Little Endian headerless WAV file	22 kHz
U_o	Channel 1	Little Endian headerless WAV file	22 kHz
P_o	Channel 2	Little Endian headerless WAV file	22 kHz
U_n	Channel 3	Little Endian headerless WAV file	22 kHz
L_x	Channel 5	Little Endian headerless WAV file	22 kHz

The resulting tracks were filtered as shown in Table 5.7. The audio files were all normalised and any DC-offset was removed using high-pass filter with a very low offset. The aerodynamic channels were low-pass filtered and the Laryngograph was high-pass filtered.

¹⁰Note that Channel 4 is the nasal pressure channel (P_n), This channel had to be excluded due to errors in the channel discovered on return from fieldwork.

TABLE 5.7: *Acoustic and Aerodynamic filtering methods.*

TRACK	POST HOC FILTERING METHOD
WAV	Normalised and then High Pass filtered at 5 Hz (to remove any DC-offset)
U_o	Low pass filtered (6-pole Butterworth filter, 45 Hz, cut-off, 256 point Kaiser window)
P_o	Low pass filtered (6-pole Butterworth filter, 45 Hz cut-off, 256 point Kaiser window)
U_n	Low pass filtered (6-pole Butterworth filter, 45 Hz cut-off, 256 point Kaiser window)
L_x	High pass filtered using a 75 Hz cut-off
G_x	Low pass filtered using a 45 Hz cut-off

The signal from the oral flow channel is integrated to give the moment of maximum rate of change in the signal. Cho and Jun (2000) used the integrated airflow to calculate the degree of glottal opening when looking at airflow in the Cheju variety of Korean.

The track names follow standard definitions for aerodynamic channels (after (Stevens, 1999)). The U_o signal is the volume velocity at the open end of a tube model (Stevens, 1999, p. 127). When the tube is taken to be the vocal cavity then the open end is at the lips and the volume of air at the source (U_s) is taken to be the lungs. In this study U_o is defined as the peak oral flow at the lips and it is measured in ml/s which is equivalent to cm^3/s at a point approximately 2 cm from the lips.

The P_o signal is the peak intra-oral pressure measured behind the lips. This is measured in Pascals (Pa) *Le Systèm International d'unités* (SI) derived unit of measurement for pressure (Shadle, 2013). The U_n signal is the volume velocity of air released from the anterior end of the nasal cavity which is measured via a flow-rate transducer connected to a nasal mask via a tube (Baken & Orlikoff, 2000, p. 474).

5.7.5 Recordings

The recordings that are analysed in this experiment are all multichannel, articulatory recordings with a number of synchronous channels. The number of channels is different dependent on the speaker. This limits the channels that can be included in the analysis. Details of the recording technique, filtering methods and preliminary analysis can be found in § 5.7.1. To summarise the details found in § 5.7.1 above; the recordings for this experiment were conducted using a multichannel aerodynamic acquisition device. The Scicon R&D airflow mask with an inbuilt microphone and transducers connects to a Scicon R&D 916 capture device (Scicon R&D California, USA). This allows the capture of both oral (U_o) and nasal (U_n) air flow and oral air pressure (P_o) records. The

pneumotachograph measurement device connects with the computer which allows temporal synchronisation and then the subsequent quantitative analysis of the raw data channels. The voice analysis reported in § 8.6, uses a subset of this corpus for which Laryngographic channels were also recorded. Figure 5.10 shows a summary of the articulatory channels recorded. This figure shows an example of a word spoken within the carrier phrase by a male speaker. The period of voicelessness is visible in the speech waveform and also the L_x (EGG) track.

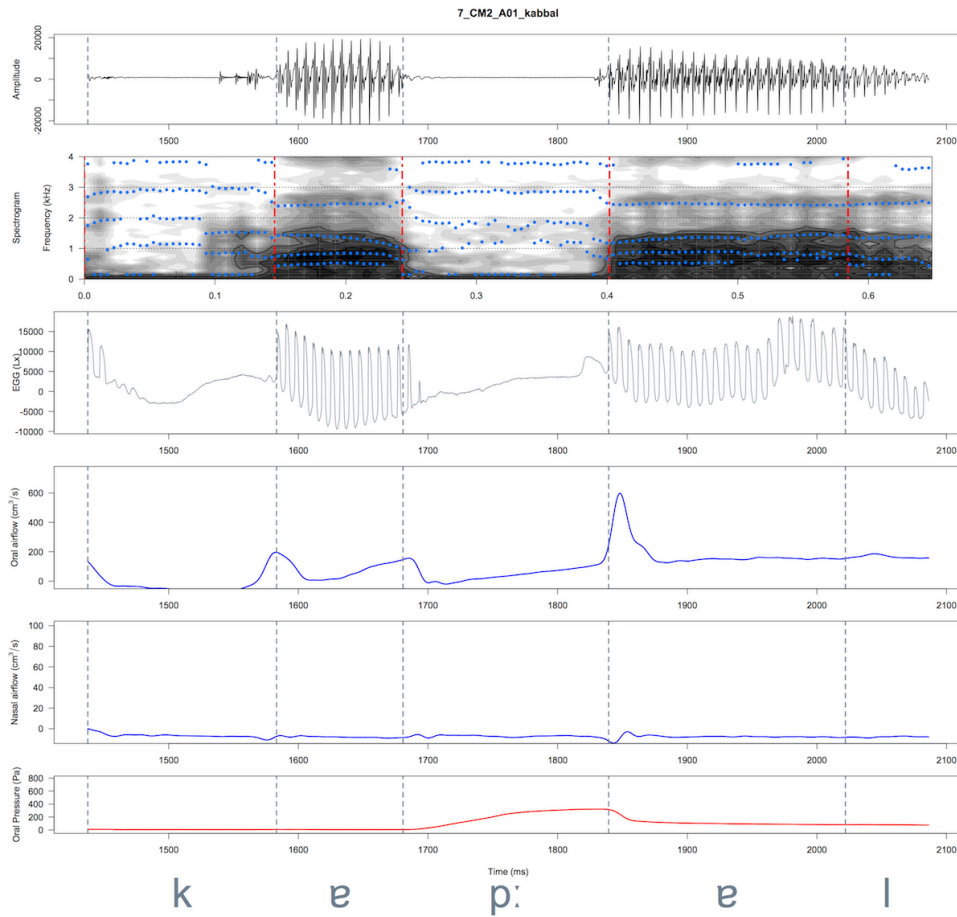


FIGURE 5.10: Waveform, Spectrogram with formant overlay, EGG (L_x), Oral airflow (U_o) measured in cm^3/s , Nasal Airflow (U_n) measured in and Intra-oral pressure (P_o) measured in Pascals (Pa), for the word kabbal for speaker CM.

Figure 5.11 shows a medial bilabial lenis stop spoken by a male. The word is in final position.

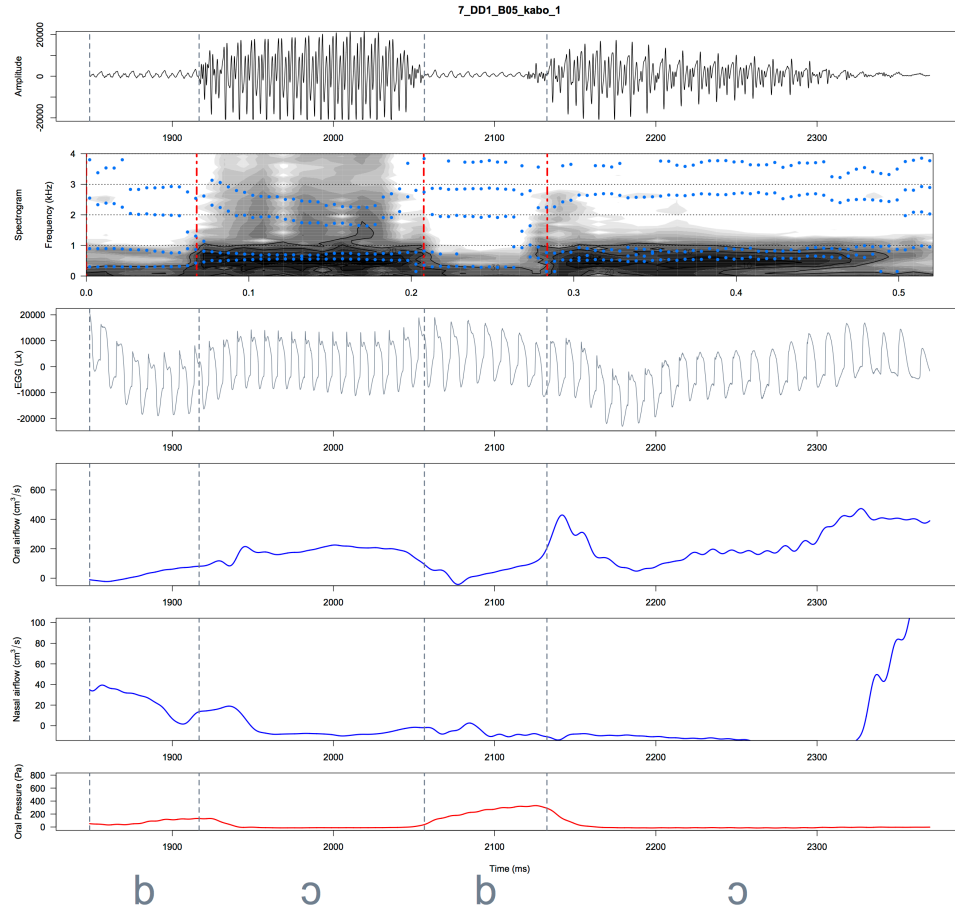


FIGURE 5.11: Waveform, Spectrogram with formant overlay, EGG (L_x), Oral airflow (U_o) measured in cm^3/s , Nasal Airflow (U_n) measured in and Intra-oral pressure (P_o) measured in Pascals (Pa), for the word bobo for speaker DD.

5.7.6 Labelling

The two figures (Figure 5.10 and Figure 5.11) show the broad phonetic labelling scheme used within the aerodynamic corpus (Corpus II). The phonetic labelling was done by hand using a combination of the Praat (Boersma & Weenink, 2013) software and The Emu Speech Database (Harrington et al., 2012). This segmentation is the basis for phonological and higher order segmentation such as splitting into morphemes or words (see § 5.4.1 for more information on criteria used). The hierarchical structure of The Emu Speech Database is crucial for

controlling the prosodic position and location of the word of the target segment. This allows high levels of control when grouping the factors and enables input into statistical models within the *R* environment (Ihaka & Gentleman, 1996).

The maxima and minima for the oral flow and pressure channels—based on a medial VC(:)(C)V sequence—were calculated automatically using a script in *R*. Turning points were found for the flow and pressure records using the first derivative of the signal and the resulting time input into separate event tier (see § 5.7.4). Additionally, the first and second derivative were calculated for the L_x channel, and this enables the calculation of the open and closed quotients. These were discarded however, in favour of an alternate method detailed below in the voice analysis using acoustic measures (§ 8.6).

5.7.7 Aerodynamic measurements

The aerodynamic measurements use words at all places of articulation but it was only possible to record synchronous intra-oral pressure in words containing bilabials. Generally across all of the aerodynamic analyses the method for recording, filtering and analysis is the same and the experiments in Chapters 6 and 7 share a basic methodology. The peak oral (U_o) and nasal (U_n) air flow was recorded as well as local maximum flows within the sequence (U_o^{MAX} and U_n^{MAX}). Where possible, intra-oral air pressure (P_o) was measured together with local pressure maxima (P_o^{MAX}). The minimum flows and pressures were also labelled separately for each segment.

5.7.8 Ratio of maximum intra-oral pressure to peak oral flow in stops

The ratio of peak oral pressure compared with peak oral flow has been shown to have linear relationship in voiceless stops. Subtelny, Worth, and Sakuda (1966, p. 508) compared mean intra-oral pressure to mean duration and also peak rate of oral flow to maximum intra-oral pressure and found this too to

be a linear relationship. Subtelny et al. (1966) also note that the relationship between these measurements are simpler than those that compare flow-pressure with sound-power measurements (i.e. burst amplitude). In a similar set of measurements Dart (1984, p. 7), compares peak flow with peak pressure. In Dart's study peak flow is plotted on the y-axis (l/s) and peak pressure is plotted on the x-axis (cm H₂O). Each point represents an average of five tokens from a single speaker. Dart (1984, 1987) used pairs of lenis and fortis stops. Dart (1987) found that the lenis stops showed greater airflow despite showing less pressure in the majority of cases. It was not possible to match minimal pairs in the current experiment as Bininj Gun-wok has only one attested minimal pair containing an intervocalic lenis and fortis stop (see § 4.5).

5.7.9 The pressure impulse

The 'Pressure Impulse', as defined by Malécot (1970), describes the peak intra-oral pressure measurements over time. The term impulse—avoided by Lisker (1970) when describing a similar measure— must be defined carefully before application. Within the field of classical mechanics, an impulse is defined as the integral of a force with respect to time. This can be represented by the following equation:

$$\mathbf{I} = \int_{t_1}^{t_2} \mathbf{F} dt, \quad (5.4)$$

where F is force and I is the resulting impulse. Pressure is the force per unit area and consequently a more complex unit than simply force. The integral of a pressure signal is not as easily defined, however. Malécot uses this base equation—the integral of force—to derive his formula for the pressure impulse. Malécot (1966b) in a companion experiment, does in fact measure the physical force applied by the primary articulator and he goes on to say that, “[a]ir pressure may well be an index of articulatory ‘force’, but it can by no means be interpreted as ‘force’ itself” (Malécot, 1966b, p. 170). Malécot rejects Stet-

son's (1951 cited in Malécot, 1966b) assumption that intra-oral pressure can be equated with the actual articulatory force of the utterance.

Keeping in mind the equation stated above in Equation 5.4, it can be shown that force is not simply equal to the intra-oral pressure alone. Malécot (1966a; 1970) expresses 'pressure impulse' using the following equation:

$$\mathbf{P_oI} = \int_0^T \mathbf{p_o} dt, \quad (5.5)$$

where $\mathbf{P_oI}$ is the peak pressure at the time t with limits at the time of closure (0) and the release (T). Malécot (1966a, 1966b) uses 'peak pressure' to refer to both peak intra-oral pressure, and also mechanical pressure to indicate greater pressure from the active articulator onto the passive articulator. Due to this varying use of the term *force* the pressure impulse can not be a measure of impulse from the standpoint of classical physics but it is a useful way of reducing a complex set of variables into a single measurement. It is for this reason that the 'pressure impulse' is reported for the current study. Unfortunately Malécot does not provide a way to calculate this easily as he estimated the area under the curve by hand marking the analogue signals (Malécot, 1966a, p. 69). For this reason, the measurements used in the current study are not a direct comparison to Malécot's 'pressure impulse' measurements. It is however possible to estimate the integral of the function of peak pressure over time which is approximately equal to the area under the curve using established mathematical proofs. To calculate the integral of a complex function such as a peak pressure curve, it is necessary to work out an estimate of the area under the curve at a given time point and then add each of these areas together. There are a number of mathematical methods that have been proposed to calculate the estimated area under the curve of a complex function. The most appropriate for this study is Simpson's rule (Thomas & Finney, 1984), which can be stated as:

$$\int_a^b f(x) dx \approx \frac{h}{3} (f(x_0) + 4f(x_1) + f(x_2)) \quad (5.6)$$

Once calculated, the number returned is approximately equal to the area under the curve (with limits a to b) with the units Pa s (Pascals by the number of seconds). This measurement can be used to compare the pressure impulse of each stop category to see if there is a difference in ‘force of articulation’ in addition to duration. It must be noted that duration is a component of the pressure impulse, which means that the duration and the pressure impulse will correlate. A longer duration may not imply a higher pressure impulse however. In the aerodynamic experiment I have modified the limits to include the entire stop including release.

What does this mean for Australian languages? Because there is no voicing distinction it is assumed from previous research that the glottis was in an adducted state for lenis stops regardless of whether they are voiced or voiceless and abducted for fortis stops—invariably voiceless. Lisker (1970, p. 223) uses the term pressure pulse to refer to “...the time integral of the pressure ... which is geometrically the area bounded by the line indicating instantaneous pressure and the baseline”. This is equivalent to the measurement shown above in Equation 5.6 and is the one used in the current experiment.

5.7.10 Interactions between oral air-flow and intra-oral pressure

Making generalisations about articulatory data across speakers is notoriously difficult. A coherent method of data reduction is an essential prerequisite to further quantitative analysis. There are however some phonetic parameters that resist quantitative description due to variability both within and between speakers.

The timing of oral airflow peaks is an example of such a parameter. As discussed in the previous section, peaks in the oral airflow are hypothesised to be related to the percept of ‘degree of voicing’. Airflow peaks are thought to correspond with rapid glottal opening gestures. These flow peaks will be masked by the oral closure. Intra-oral pressure rises can provide certain levels of informa-

tion regarding the timing of flow through the glottis, but an increase in glottal flow is only one way in which the intra-oral pressure can be raised. Tightening the muscles of the cheek—primarily the shallow masseter muscle (Gick et al., 2012)—and in addition raising the larynx can also increase the intra-oral pressure if the glottis is closed such as in ejective articulations.¹¹ In an ejective, the glottis is closed and then the larynx is raised upward so that the air in the vocal tract is compressed. The pressure behind the closure is often increased to double the normal pulmonic pressure; Ladefoged and Maddieson (1996) report a pressure of about 8 to 16 cm H₂O. The oral closure is then released and owing to the greater supraglottal pressure there is a greater amplitude in the stop burst. Biniñ Gun-wok consonants have not previously been described as ejectives. Certainly if they are, they could only be weakly ejective. The aerodynamic records when coupled with electroglottographic information may be able to shed light on the precise timing of these articulations and whether they can be described as ‘glottalised’, as with sonorants in Yapese (Maddieson & Larson, 2002).

5.7.11 Timing measurements

To quantify the timing of the peak oral airflow, the time it takes for the airflow peak to occur is measured with respect to the vowel. This is termed ΔU_o^{MAX} . For this measurement, aerodynamic records of words containing medial stops at all places of articulation are included.

¹¹Ejectives are not unusual sounds cross-linguistically and they occur in about 18% of the languages of the world according to UPSID (Ladefoged & Maddieson, 1996).

5.8 The method for the analysis of geminates and voicing

The acoustic and aerodynamic method is shared with other experimental chapters. The recording method and subsequent statistical analysis is the same. The speech data for the acoustic component of the experiment are drawn from both corpora. The aerodynamic data are from Corpus II and the data for the voice analysis also from Corpus II. The words are drawn from the word lists at the start of Chapters 7 (in § 7.2.2) and 8 (in § 8.1.3).

5.8.1 Voice analysis

To investigate the glottal tension at the transitions at the edges of medial consonants a comprehensive voice analysis was conducted using both acoustic and electroglottographic signals. In order to measure vocal fold activity, a Laryngograph (Laryngograph Ltd., London) is connected to the recording setup in addition to the aerodynamic equipment described above in § 5.7.1. This enables the recording of time-synchronised audio, aerodynamic and electroglottographic recordings.

The Laryngograph device was developed in the Department of Phonetics and Linguistics at University College London (Abberton, 1972; Abberton & Fourcin, 1997). The device enables “... the monitoring of vocal fold activity by means of superficially applied electrodes, and the waveform of its output, L_x (which contains no explicit supraglottal information), gives information about the frequency and mode of vibration of the vocal folds” (Abberton, 1972, p. 69).

The Laryngographic signal comprises two integrated components that can be separated using frequency dependent filtering:

- The high frequency signal, L_x records the glottal pulsing (the same information which is filtered from the aerodynamic data).

- The low frequency signal, G_x which is associated with gross movements of the larynx such as swallowing and glottal raising or lowering.

In this study, the EGG signal from the Laryngograph has been left unfiltered to retain the G_x information. The high frequency component is referred to using the abbreviation L_x , regardless of whether or not the signal has been lowpass filtered. This filtering does not affect the temporal information.

5.8.2 Glottal activity

As discussed above, a common application of electroglottography is in the measurement of voice quality. Whether a speaker's voice quality is breathy or creaky can be inferred usually by measurements of the EGG signal within a vowel. Glottal activity in Bininj Gun-wok was observed using a Laryngograph which measures impedance to record glottal activity. In the present study, laryngographic measurements coupled with aerodynamic measurements are used to infer the state of the glottis at the peripheries of the medial consonant. Three segmental environments were examined; sequences of VCV; VC:V and VC + CV, where this last sequence consists of two homorganic consonants that span a morpheme boundary. Glottal activity was measured as a means for inferring the state of the glottis at both the closure of the articulators and at the point of release directly after the onset of regular voicing.

The speakers in this study all have a high incidence of vocal fry or creaky voice. This is more evident amongst the male speakers rather than the female speakers. The overall creaky vocal setting is more noticeable in quiet (low amplitude) speech. This style of speech uses comparatively low energy from a respiratory point of view. In higher speech amplitude exchanges—calling people at a distance for example—the vocal quality generally becomes more modal.

5.8.3 Measurements

There are a number of methods for calculating not only the rate of vibration in the vocal folds but the glottal aperture. Indirectly the rate of vibration can be inferred using the Fundamental frequency (F_0) of the acoustic signal. The rate of vibration can also be measured using the L_x signal to obtain the derived fundamental frequency measure F_x .

To extract the contact quotient measurements, the raw *PCQuirer* files were input into *EGGworks* (Tehrani, 2011), which allows the EGG track to be extracted, smoothed and analysed. The *EGGworks* software calculates a number of different implementations of the closed quotient metric to be calculated directly from the EGG signal as recorded by *PCQuirer* (see Figure 5.12). The closing quotient (CQ) measurements mainly differ dependent on the threshold values used when calculating a single period of a glottal pulse measured from the EGG signal (Rothenberg & Mahshie, 1988). These alternative CQ measurements with a variety of threshold values each have their individual advantages and disadvantages which are discussed briefly here.

The principal measurements that are calculated from the EGG signal are as follows (This information comes directly from the *EGGworks* Help file within the EGG software (Tehrani, 2011)):

- **CQ:** Closing Quotient calculated using the method described in Baken and Orlikoff (2000, pp 426-7) and Orlikoff, Baken, and Kraus (1997).
- **CQ_H:** Closing Quotient calculated by the ‘hybrid’ method introduced by (Howard et al., 1990, p. 164), where the closing peak in the first derivative (DEGG) is used as the moment of closing, while the threshold in the EGG signal (with the threshold set to 3/7 of the total amplitude of the signal) is used for the moment of opening (see Figure 5.12).
- **CQ_PM:** Closing Quotient is calculated from the derivative of the EGG. The closing peak in the derivative (the maximum positive rate of change)

is used as the moment of closing, and the opening peak in the derivative (the maximum negative rate of change) is used as the moment of opening.

- **CQ_HT**: In this method the CQ is calculated by Tehrani's method: the closing peak in the derivative is used as the moment of closing, and the y-value of the EGG signal is found at the time of that peak. That y-value then is found on the opening phase of the EGG signal, and its time taken to be the time of opening.

Two further measures were extracted using the derivative of the EGG signal as a basis:

- **Peak Vel**: The maximum value of the derivative of the EGG signal (see Figure 5.13), in the increasing part of the cycle (this is the peak increase in contact (PIC)). This is based on Michaud's (2004) DECPA (Derivative-EGG Closure Peak Amplitude) measure (shown in figure 5.15).
- **Peak Vel Time**: The time at which the peak velocity value (PIC) occurs.

Each of these measures is summarised in the Figures 5.12, 5.14 and 5.15.

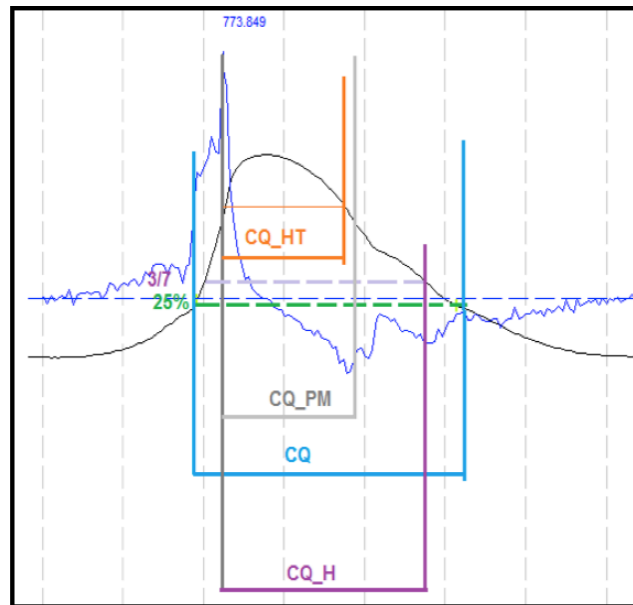


FIGURE 5.12: The measures output from EGGWorks (Tehrani, 2011) showing CQ, CQ_H, CQ_PM and CQ_HT. This figure is reproduced from (Keating et al., 2012).

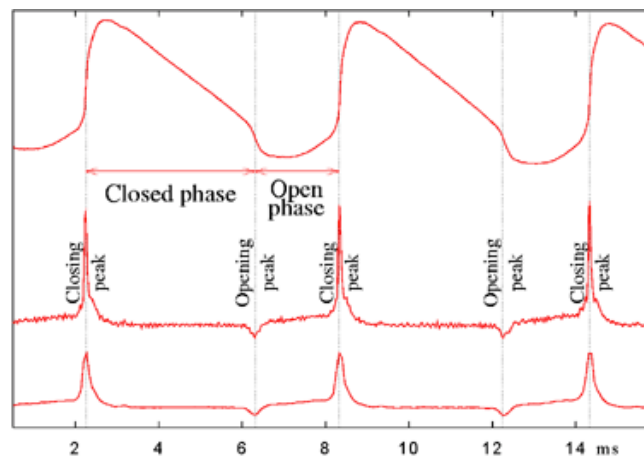


FIGURE 5.13: An illustration of the L_x signal and the peak of the first derivative (un-smoothed and smoothed) of the signal which coincide the moment of glottal closure, (from <http://voiceresearch.free.fr/egg/>).

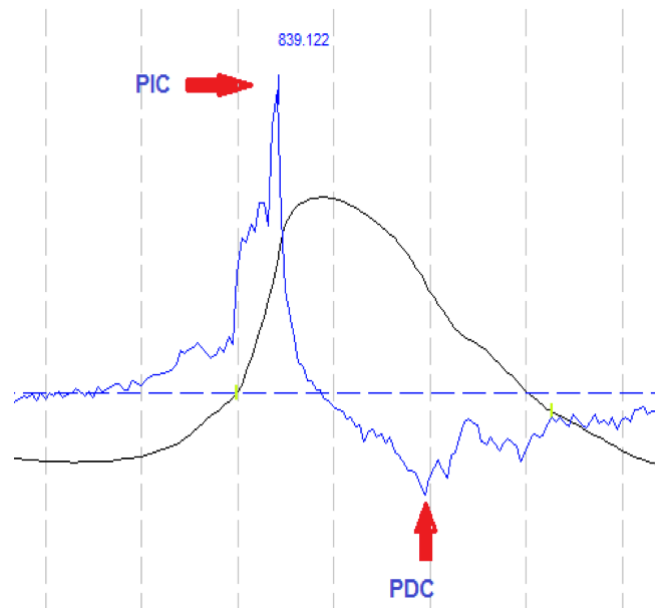


FIGURE 5.14: The derivative of the signal (DEGPA or DEGG) and the peak increase in contact (PIC) which indicates the peak velocity, figure reproduced from (Keating et al., 2012).

Skew quotient (SQ)—also known as kurtosis or speed quotient—was measured. Skewness measures the degree of symmetry in a waveform. Skewing to the left is said to correlate with the level of creaky phonation in an L_x trace (Watkins, 1997). Figure 5.15 shows how the measurements of SQ are calculated by EGGWorks. If the closing phase has a longer duration than the opening phase then the signal would be skewed to the right and conversely if the opening phase has a longer duration than the closing phase then the signal would be skewed to the left. In modal voice the closing phase is generally shorter than the opening phase.

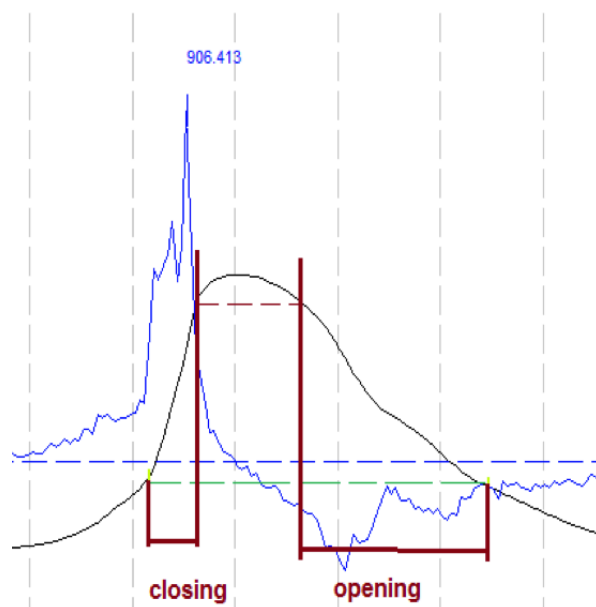


FIGURE 5.15: Measure of skew or speed quotient showing the closing and opening phases, figure reproduced from (Keating et al., 2012).

5.8.4 Spectral tilt and power spectra

In this section I will detail the spectral acoustic measurements that will be carried out in this experiment. Measurements of different portions of the power spectrum can provide information on phonation types. By examining different spectral frequencies it is possible to infer the phonatory setting used by a speaker in an utterance. These spectral measurements can be broadly placed into three classes. Firstly, those that compare frequencies in the lower range of the speech spectrum. Secondly, those that use the middle of the speech spectrum and thirdly those that use the upper ranges of the speech spectrum (DiCanio, 2009, p. 168).

Some measurements of spectral tilt are shown in Figure 5.16. The first two harmonics are labelled $H1$ and $H2$ and the amplitude peaks $A1$, $A2$ and $A3$ respectively. $H1$ and $H2$ refer to the first two harmonics. $A1$, $A2$ and $A3$. Figure 5.16 shown the most prominent amplitude peaks at the onset of a vowel [æ]

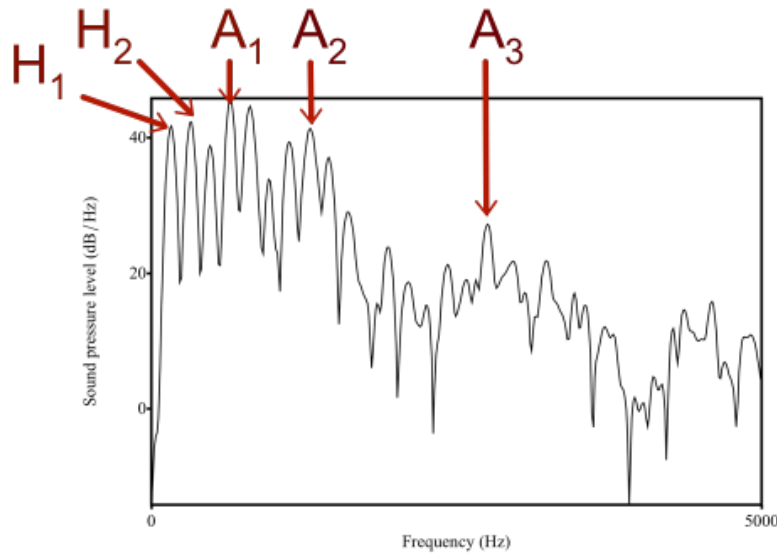


FIGURE 5.16: Spectral measurements on a spectral slice of a speech waveform..

The analysis for the current investigation was carried out using “*Voicesauce*”, developed for the UCLA ‘Production and Perception of Linguistic Voice Quality’ project Shue et al. (2011, 2009) run within the MATLAB environment (MATLAB, 2012). The program, was used to extract the various spectral measurements and to integrate the EGG analysis derived by *EGGworks* (Tehrani, 2011).

Voicesauce allows for a variety of spectral measurements using the acoustic signal as input. These spectral measurements are summarised in Table 5.8.

TABLE 5.8: Voice analysis measurements output from *Voicesauce* Shue et al. (2011, 2009).

MEASUREMENTS	H1-H2	H1*-H2*	H2-H4	H2*-H4*
	H1-A1	H1*-A1*	H1-H2	H1*-A2*
	H1-A3	H1*-A3*	Energy	Cepstral Peak Prominence (CPP)

The starred versions of each of the spectral measures (H1*-H2*, H2*-H4*, H1*-A2*, H1*-A3*) are corrected measurements using both F_0 and formant values and where available the EGG signals to correct for their effects. The method

used to derive these corrected values is detailed in Iseli, Shue, and Alwan (2007). In the current study synchronous EGG signals have been recorded for a subset of data allowing the investigation of any correlation between *OQ* or *CQ* and *H1-H2* (or the adjusted measure *H1*-H2**).

The main measures used in this study are those that can provide information about glottal tension. These are principally found in the low-range measures such as *H1-H2*. This measure has a close correlation to open quotient (*OQ*) values—the inverse of the *CQ* measurement. This can provide a good measure of the degree of glottal tension present in different phonation types (Holmberg, Hillman, & Perkell, 1988; Stevens & Hanson, 1995; Sundberg et al., 1999, cited by DiCanio, 2008). To investigate if there are any observable differences in the muscular tension of the vowels surrounding medial lenis and fortis stops in Biniŋ Gun-wok the *CQ* and *H1*-H2** have been measured (along with the other measures introduced above).

5.9 The method for the analysis of nasals

The third and final experiment (Chapter 9) uses both acoustic and aerodynamic recordings to investigate nasal articulation in Biniŋ Gun-wok and coarticulatory effect with the surrounding segments. The oral flow (U_o) and nasal (U_n) flow channels along with the acoustic information form the basis of the analysis. The method for data capture is identical to the previous experiments for aerodynamic and acoustic recordings and has been detailed above. Durational results derive from a combination of these acoustic recordings.

Nasal aerometry is an ideal way to indirectly measure the levels of velopharyngeal port (or velum) opening in a non-invasive way. This allows a researcher to infer movements of the velum and to extrapolate co-ordination between the velum and the anterior articulators in combination with the acoustic signal. Aerometry can yield very fine-grained spatial and temporal information

regarding the onset and offset of nasalisation in relatively natural connected speech. Each of these advantages have been noted by Delvaux et al. (2008) in a study of nasal coarticulation in French. Nasal aerometry is a widely accepted method for capturing information about changes in the nasal subsystem and has been used in many previous studies on coarticulation (for example Bell-Berti, Krakow, Gelfer, & Boyce, 1995; Bell-Berti & Krakow, 1991; Krakow & Huffman, 1993).

Aerometry provides no direct information about place of articulation however. This limitation was taken into consideration in the design of the experiment summarised in this chapter. Place of articulation was controlled for and results for each place of articulation are given separately for the purposes of comparison. There is seemingly little influence from the suprapharyngeal articulators on nasal flow patterns apart from the interaction of velum lowering on very posterior articulations such as velars and uvulars. In nasal airflow patterns there only very subtle effects and this is logically because the air is redirected into the nasal cavity and away from the oral cavity before any interaction with the articulators. The addition of oral flow recordings does allow the timing of an oral occlusion to be inferred. This is pertinent when examining phonetic prestopping and the exact timing of velum lowering in those articulations.

The nasal analysis is split into three parts some of which explore Butcher's observations regarding nasal assimilation in Australian languages (Butcher, 1996, 1999, 2006a). The first two parts start with methods developed in phonetic analyses of French nasalisation (Basset et al., 2002; Delvaux et al., 2008). The third part of the experiment looks at the nasal airflow patterns of single nasals and clusters informed by gestural dynamics.

5.9.1 Speakers and materials

Aerometry is the ideal measurement technique for examining nasal articulation, particularly coarticulatory effects (as detailed above in § 5.7). This ex-

periment involves the analysis of acoustic and aerodynamic recordings which are drawn exclusively from Corpus II (see § 5.1). Six female speakers of Bininj Gun-wok (Kunwinjku) were recorded repeating a word list which focuses on medial nasals. Three repetitions of the word list were completed for each speaker giving a total of 1233 tokens.

As in the approach taken for Chapters 5 and 6, the target words were embedded in a carrier phrase presented to the participant in the following form:

- (5.7) Yuwun yiyime **kinga** yiyimen **bimmak**.
 PROHIB 2/3.say.NP ‘crocodile’ 2/3.say.NP ‘painting’ ‘good’.
 ju:n 'i:mɛ 'kiŋɐ 'i:men 'bim'ɛk
 ‘You don’t say ‘crocodile’, you say ‘good painting’.

An extensive word list was recorded but to control for place of articulation and word stress a limited set of tokens were used in the construction of this experiment. The word list is shown in Table 5.9 and the full list can be found in the Appendix (Appendix B.2—Corpus II—Nasal List):

TABLE 5.9: *Nasal word list (N).*

ID	WORD	PHONETIC	STRUCTURE	GLOSS
N01	kunak	[^h kʊnɛk]	VNV	<i>fire</i>
N02	kamak	[^h kɛmɛk ^h]	VNV	<i>good</i>
N03	bininj	[^h pɪnɪŋ]	VNV	<i>man/male</i>
N04	kangokme	[kɛŋɔkmɛ]	VNV	<i>straight ahead</i>
N06	karnubirr	[^h kɛŋʊbɪr]	VNV	<i>fresh water mussel sp.</i>
N07	kinga	[^h kiŋɐ]	VNV	<i>Crocodylus porosus</i>
N08	borndok	[^h pɔŋdɔk]	VNCV	<i>spear thrower</i>
N09	kunburrk	[^h kʊnbʊrk]	VNCV	<i>shape/form of a body</i>
N10	kunkurlba	[kʊn'gʊlpɛ]	VNCV	<i>blood</i>
N11	manbandarr	[mɛn'bɛndɛr]	VNCV	<i>Turkey Bush</i>
N12	kanjdji	[^h kɛŋɔɟɪ]	VNCV	<i>low/under</i>
N05	bongdi	[^h pɔŋdɪ]	VNCV	<i>trapped</i>
N13	bedmanwali	[^h pɛd'mɛnwɛli]	VCNV	<i>their turn</i>
N14	woknang	[^h wɔknɛŋ]	VCNV	<i>said goodbye</i>
N15	rlobmeng	[^h rlɔpmɛŋ]	VCNV	<i>arrive (past)</i>
N16	bebmeng	[^h pɛpmɛŋ]	VCNV	<i>arrive (past)</i>
N20	bimmak	[^h bim:ɛk]	VNNV	<i>good painting</i>

In sequences of $V_1N_1V_2$, $V_1C_1N_1V_2$ and $V_1N_1C_1V_2$, duration is measured along with the durations of anticipatory and carry-over nasalisation using aerodynamic channels. Single nasals and both homorganic and heterorganic clusters of nasals and stops are measured for the six speakers of Bininj Gun-wok.

In terms of distribution within the lexicon, homorganic stop plus nasal (C_iN_i) sequences are found less commonly than heterorganic sequences (C_iN_j).¹² There are stop-nasal sequences at some places of articulation that are entirely absent from this corpus. This does not imply that they are not found in the language at all, but extensive elicitation and consultation with Kunwinjku speakers along with consultation of the written language resources did not uncover any example words containing these clusters. Apico-alveolar homorganic clusters (/dn/) are common in the Eastern dialects of Bininj Gun-wok such as Kuninjku and Kune. This is because the nominal suffix *-no*—cognate to the Class-IV Nominal prefix *kun-* in Kunwinjku for inanimate objects—is a very common word final morpheme (Evans, 2003). The proper noun *Kundedjnjenghmi* (the name of a Bininj Gun-wok variety) contains an homorganic palatal cluster /cp/ which is an example of one of the under-represented homorganic stop plus nasal sequences. It should be noted that the medial homorganic palatal stop plus nasal cluster contains a palatal fortis stop in the first position.

Velars in Bininj Gun-wok—and Kunwinjku in particular—have articulations that are allophonically uvular for the velar phoneme, as discussed in § 4.4.1. This uvular allophone of velars is more prevalent in a back vowel environment. Graetzer (2012, p. 242) has shown experimentally in a number of Australian languages that the anteriority of constriction varies at the same place of articulation in accordance with the following vowel environment.

¹²where i and j are different places of articulation.

5.9.2 Acoustic duration measurements for nasals

The durations are labelled on a segmental phonetic tier (*phonetic*) using the acoustic waveform and spectrographic information. They do not make reference to aerodynamic data. The subsequent measurements are based on the measurement criteria set out in the methodology section (see § 5.4.2 on page 116). The duration of a nasal was measured from the offset of regular high frequency activity (> 2000 Hz) in the spectrogram along with strong antiformant activity the frequencies of which are dependent on place of articulation. This period is taken to be the time in which the articulators had fully occluded the oral cavity. The offset of the nasal is measured from the onset of high frequency energy in the following vowel. Duration measurements were taken for the nasals, stops and clusters all in word medial position. The duration measurements are reported below in §9.2.1 (Durations) in Tables 9.1 to 9.6 on pages 279–285. Nasalisation is a gradient phenomenon and nasals are relatively sonorous making it difficult to place discrete boundaries on the transition between vowel and nasal. These discrepancies between the acoustically based labelling and the information in the nasal flow channel will be discussed further after the presentation of aerodynamic results.

The duration measurements examine single nasals and nasals in clusters. The duration measurements will be frequently referred to in the course of the analysis particularly when discussing the aerodynamic results. The aerodynamic component of the experiment is split into three sub-experiments, all testing the extent and directionality of nasalisation in Bininj Gun-wok in light of Butcher's observations regarding velar timing in other Australian languages (Butcher, 1999). The initial two sub-experiments have methodological frameworks based on those developed for examinations of French nasalisation. The final descriptive section looks at possible applications of an articulatory phonology model to nasals in Bininj Gun-wok and discusses some of the implications.

5.9.3 Aerodynamic measurements for nasals

Aerodynamic techniques are among the most reliable methods for inferring the activity of the velo-pharyngeal port. However, the speaker specific nature of aerodynamic data make them difficult to compare across speakers. Each speaker has a different lung volume and potentially a different flow rate during exhalation. These parameters cannot be easily estimated by observation of the sex and physical size of a speaker. The flow-rates are highly stable particularly within speakers. Multiple repetitions are have very similar peak values speaker-to-speaker (Baken & Orlikoff, 2000, p. 355). This variability in the timing and intensity of airflow in speech makes it necessary to use data reduction and normalisation techniques such as estimation of curves and time-normalised averaging. This must be done before the dataset can be further analysed.

Measurements include the mean oral airflow rate ($\overline{U}_o$)(measured in $\text{cm}^3 \text{s}^{-1}$), the mean nasal airflow rate ($\overline{U}_n$) (also measured in $\text{cm}^3 \text{s}^{-1}$) and the proportional measurement of nasal flow (U_n) when compared with the total flow ($U_o + U_n$) of a segment $\frac{U_n}{U_o + U_n}$. This final proportional measurement has been chosen as it is largely insensitive to gross variation in the total airflow of the system (oral and nasal airflow combined). Consequently, it is a more appropriate measure for comparing the airflow results across different speakers. Comparing across speakers is not ideal however, as there are differences in the overall lung volume dependent on the physical size of the speaker and this could possibly change rates of flow. The amplitude of the utterance too changes the rate of flow and some speakers were markedly louder than others when repeating the word list.

When calculating average flow across time, all words that are included in the final calculations have initial velar oral stops [k]. The word *bininj* (N03 in Table 5.9) is excluded from this analysis in an attempt to control for any phonetic effects from segments preceding the medial nasal. It was not possible to control for vowel quality, however, due to the relatively small sample size

of this corpus. In addition to these considerations, nasal initial words were excluded due to possible effects of carry-over nasalisation from the initial nasal. There are nasals present in the carrier phrase (see § 5.9.1) which may introduce long range carry-over effects, but as the carrier phrase being held constant the potential effect on the results are thought to be minimised.

Similar measurements to those reported for French by Delvaux et al. (2008) have been used in Chapter 9. See § 3.1.2 on page 61 for a summary of previous literature on the analysis of nasals in French. In the analysis of anticipatory nasalisation the nasal flow is averaged across all speakers in an effort to show patterns of timing similarity rather than providing information about absolute rates of flow.

The averaging of airflow is achieved by first, time normalising the signal and subsequently, averaging each segment in the sequence separately giving an average peak flow over time (U_n) (Delvaux et al., 2008, pp 594–5). This method has proven useful for showing the timing of airflow rises although the flow magnitude information—as it is an average across speakers—is less informative. In Figure 5.17 a sequence of three word medial segments are shown, an intervocalic nasal surrounded by two vowels (V_1NV_2). As each of the segments has been time normalised (shown in Figure 5.17 as **T** for each segment) the relative durations of the segments—particularly in the clusters—is lost. This will be discussed further below.

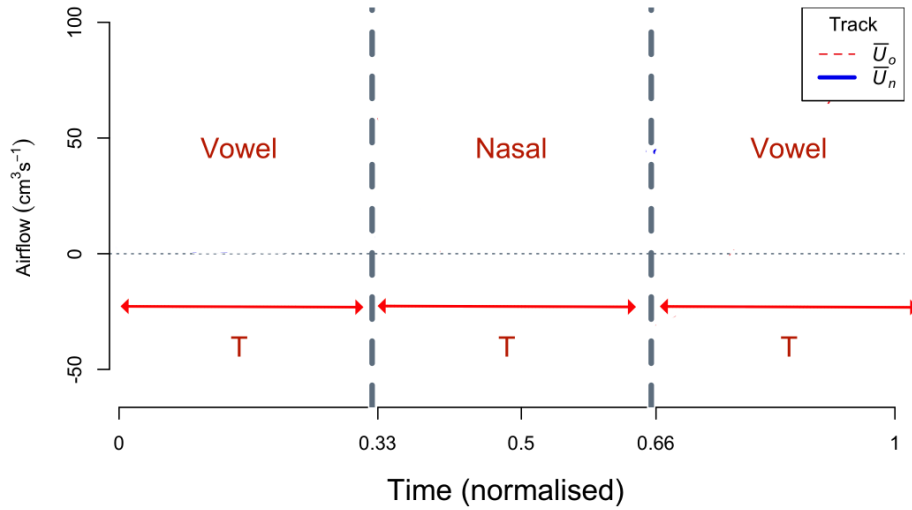


FIGURE 5.17: *Normalised time and averaged airflow (after Delvaux et al., 2008).*

The relative timing of the segments will be discussed further with reference to the duration measurements and also timing in relation to the nasal airflow peaks. The relative timing measurements are most relevant for examining the nasals contained in clusters.

5.9.4 Aerodynamic timing measurements

The presence of airflow peaks in the signal make it possible to infer the timing of the maximum opening of the velum. The associated oral closure, for the most part, does not interfere with the velum lowering. By measuring the time at the onset of nasal airflow in relation to the point of closure using information from the nasal flow channel (U_n) it is possible to quantify the amount of anticipatory and carry-over nasalisation present using the nasal flow channel (U_n) (Basset et al., 2002).

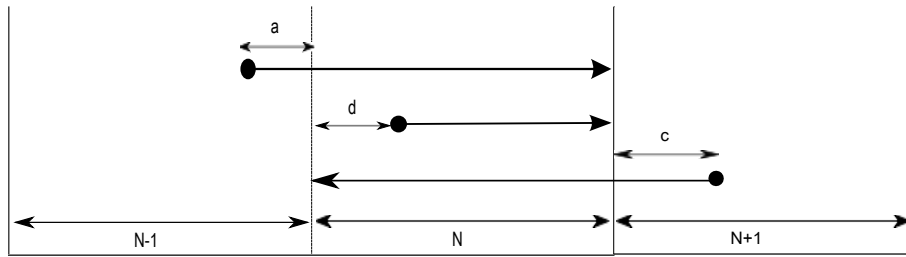


FIGURE 5.18: The measurement criteria for estimating anticipation and delay of the onset of nasal air flow, after Basset et al. (2002).

In Figure 5.18 the value ‘a’ represents the duration of anticipatory nasal airflow. The interval (a) is measured as the time between the onset of nasal airflow represented in the nasal flow channel (U_n) and the onset of the nasal consonant determined from the acoustic signal. The onset is the zero point, marked in the figure using a dotted line. The interval ‘a’ will return a negative value. If there is a delay in the onset of nasal airflow then this is measured as ‘d’ and returns a positive value. The nasal segment is marked ‘N’, and the preceding segment is marked ‘N-1’. The following segment is ‘N+1’. The interval marked ‘c’ is the time of carry-over nasalisation from the offset of the oral closure in the nasal until either a minimum in the nasal flow channel or the end of the vowel (V_2), whichever come first.

A further timing measure calculates the maximum rate of change in the nasal airflow to infer the point in which there is active opening of the velum. To determine the maximum rate of change the first derivative of the function corresponding to the nasal curve ($f'(U_n)$) is calculated (see § 5.7.4). Although the nasal channel is low pass filtered, the resulting signal has residual voicing frequencies that are not able to be removed without negatively impacting the timing information in the signal. Consequently, prior to calculating the first derivative of the curve, the wave must be approximated using a discrete cosine transformation (DCT) as detailed in Harrington (2010, pp 205–6). The resulting signal is then able to be differentiated successfully. The maxima and minima of

this differentiated signal are taken to be the peak velocity of the opening and closing gestures in the velum which is also the greatest change in velocity of the nasal flow rate. It is possible to calculate the acceleration using the second derivative of the original signal ($f''(U_n)$). This derived measurement has not been used in the analysis for Chapter 9, but will be used for future investigations into nasalisation in Bininj Gun-wok.

Chapter 6

An acoustic analysis of stops

The phonetic correlates of the lenis/fortis contrast in Biniŋ Gun-wok are examined with both durational and non-durational aspects of stop production are measured. This follows on from previous research methodologies applied to European languages. Evaluation of medial stop durations—both total duration of the stop and also closure duration—are reported to look at place of articulation effects (§ 6.3). The results of an analysis of voice onset time for medial stops is presented in § 6.5.1 and the results of an analysis of voice termination time is described in § 6.5.3. These measures are evaluated in order to assess voicing patterns and the stop contrast, particularly the variation in lenis stops. Finally, non-temporal aspects of the speech signal such as the spectral characteristics and amplitude of the burst are measured at the release. The amount and directionality of place assimilation and coarticulatory effects may provide cues to a difference between the stop categories. Locus equations may show that the medial position is an important prosodic position for strengthening place cues. This chapter provides important groundwork for the subsequent experiments (Chapters 7 and 8) in which a physiological examination of Biniŋ Gun-wok medial stops is reported. The motivations for this experiment, details of the corpora and measurement criteria are discussed in Chapter 5.

6.1 The Aims, hypotheses and research questions

The hypothesis set out § 5 state:

H1. Duration is the only reliable acoustic phonetic difference separating lenis and fortis stops.

H2. Voice onset time and voice termination time are not sufficient as phonetic cues to a difference between the stop types.

Initially H1 will be tested (see § 4.1).

Some further questions posed by these hypotheses are:

Q1. Is duration a consistent cue to a difference between medial consonants either in the consonants or in duration of the surrounding vowels?

Q2. Are there any non-temporal cues such as differences in burst amplitude that are independent of place of articulation?

Q3. Is there stability evident in the F_2 transitions of VC and CV sequences and are there any differences between the stop categories?

There is evidence from a variety of languages (see § 2.1.1, § 2.1.2 and § 2.2), that non-temporal phonetic aspects such as burst amplitude contribute to the perception of stop contrasts in a particular language. In this chapter, these research questions and in addition those outlined in § 4.5, will be investigated and the hypotheses tested using acoustic techniques.

6.2 The methods and materials: acoustic analysis

In the following experiment the lenis and fortis stops have been measured in a word-medial intervocalic position. Single stops do not normally occur in this environment and clusters of stops are much more common in Biniŋ Gun-wok morphology. There is further discussion of clusters and cluster duration in § 8.2.

The environment V_iCV_j for intervocalic lenis stops and $V_iC:V_j$ for intervocalic fortis stops are included where the vowels V_i and V_j may either have the same or different vowel qualities. The general experimental method and additional technical information regarding the corpora used in the analytical core of this chapter can be found in Chapter 5. The methodology specific to this chapter is presented in § 5.6.

6.3 Results: acoustic duration

Total consonant duration measurements are summarised in Table 6.1, showing a clear difference between the means of the two groups. As shown in Table 6.1 the lenis group has a mean duration of 76 ms and the fortis group a mean duration of 161 ms.

TABLE 6.1: Mean ($\bar{x}$), standard deviation (σ) and minima and maxima for lenis and fortis medial stop durations, measured in milliseconds (ms).

	$\bar{x}$	σ	<i>min.</i>	<i>max.</i>
FORTIS	161	33	76	298
LENIS	76	28	17	197

When combining duration measurements from both accented and unaccented words within a phrase. The prosodic aspect of the word within the category is an additional variable that requires control. To test for influences of a word's position within the phrase, the target words that contain medial stops were separated into two groups. Those that occur in first position within the carrier phrase (focussed, i.e., *kabbal* in Example 6.1) and those in second position in the carrier phrase (unfocussed, i.e., *kakkak* in Example 6.1). The results of a statistical analysis of position in the carrier phrase are summarised in Tables 6.2 and 6.3.

- (6.1) Yuwun yiyime **kabbal** yiyimen **kakkak**.
 PROHIB 2/3.say.NP 'flood.plain' 2/3.say.NP 'MM.or.MF'.
 ju:n 'i:mɛ 'kɛp:ɛl ʲi:,mɛn 'kɛk:ɛk

‘You don’t say ‘flood plain’, you say ‘mother’s mother, mother’s father or daughter’s/son’s child (maternal grandparent and reciprocal grandchild)’.

Within the sample there are 468 words containing fortis stops in the focussed position of the carrier phrase and 300 words containing lenis stops in the focussed position. In the unfocussed position of the utterance there were 413 words containing fortis stops and 135 words containing lenis stops in the same position. The two samples have roughly equal variance and are normally distributed.

TABLE 6.2: *Summary of statistical analysis for lenis and fortis medial stop durations for tokens in position 1 (focussed) in ms.*

	$\bar{x}$	σ	<i>min.</i>	<i>max.</i>
FORTIS	160	31	87	298
LENIS	82	27	18	182

TABLE 6.3: *Summary of statistical analysis for lenis and fortis medial stop durations for tokens in position 2 (unfocussed) in ms.*

	$\bar{x}$	σ	<i>min.</i>	<i>max.</i>
FORTIS	163	29	97	237
LENIS	77	24	26	167

The tables show that the mean ($\bar{x}$) and the standard deviation (σ) for total stop duration is similar for words in focussed and unfocussed position. Tokens in the focussed position are summarised in Table 6.2. The focussed tokens show a larger range of values than tokens in unfocussed position, as shown in Table 6.3. This suggests that when a token is in the focussed position it is more carefully articulated.

Tokens in both focussed and unfocussed positions may be articulated differently and to lessen possible effect of ‘*token position*’ it is treated as a random factor when constructing linear mixed effects models. Additional random factors include are ‘*speaker*’, ‘*repetition*’ and ‘*year of recording*’. In the current study,

using tokens from both focussed and unfocussed positions has been avoided where possible and token position will be explicitly stated in each case.

6.4 Total medial stop duration

Figure 6.1 shows the durations of the fortis and lenis stops and it shows a clear durational difference between the medians ($\tilde{x}$) of the two groups.¹ Additionally the standard deviations (σ) have similar distributions. This clearly shows that there is a basis for the phonological categories.

The outliers shown in Figure 6.1 are not excluded from the analysis. Importantly, these pooled duration results do not reflect the high levels of interspeaker variability found within this large sample of the population. Interspeaker variability and the interactions of stop category with place of articulation are presented in finer detail below.²

In general, the lenis stops are voiced whereas the fortis stops are invariably voiceless for the majority of the closure duration. There is greater variation with both voicing and devoicing within the lenis category and the duration of voicing is highly dependent on duration. Only 40% of the lenis stops are devoiced for the entirety of the closure. The fortis stops, in contrast, have no tokens with voicing throughout the entire closure. The variation within the lenis group is partially explained by place of articulation and speaker specific differences but this is not the only source of variation. This will be discussed in greater detail below.

¹The median ($\tilde{x}$) is shown as a horizontal line on the box plots and the top of the box represents the inter-quartile range.

²The outliers in the initial recordings are spoken at a significantly slower speech rate. These slow-speech sessions often involved the participants checking the word list for accuracy and as mentioned in the method these were in a pedagogical frame as the author was being taught new vocabulary items. These initial sessions were intended to be supplemented by a subsequent recording session but that was not always possible and so they have been included in the analysis.

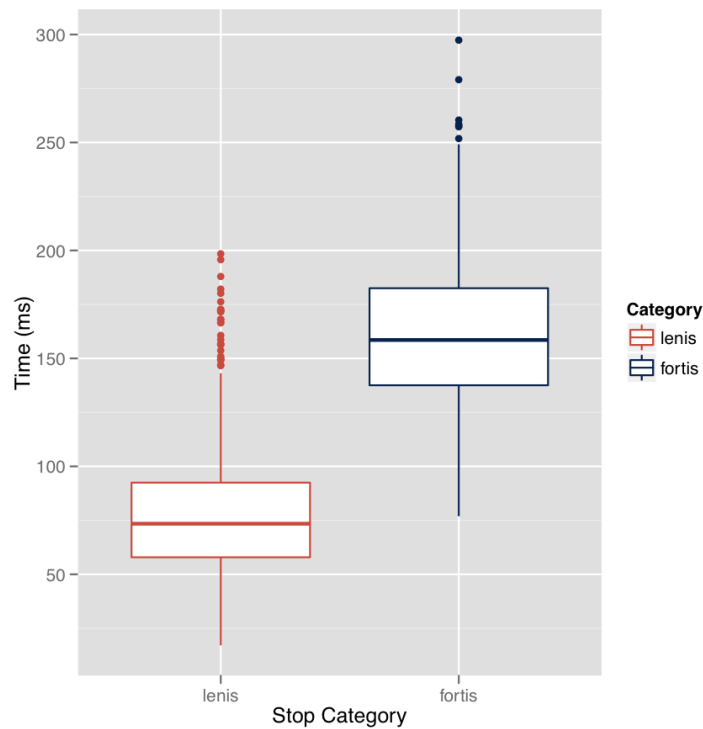


FIGURE 6.1: Stop durations separated by phonological stop category.

The mean duration is compared within the lenis stops in order to investigate any differences between voiced lenis and voiceless lenis stops. To test interactions a LMEM is used with voicing included as a fixed factor, with two levels, voiced and voiceless. Speaker and token are included as random factors and the subsequent likelihood ratio proves to be significant ($\chi^2(5, N = 2461) = 199$, $p < .001$). The results of a *post hoc* Tukey HSD test show that there is a significant difference between the voiced and the voiceless groups ($p < .001$) with the voiced group showing a mean duration of 74 ms and the voiceless group showing a mean duration of 99 ms. A summary of the separating tokens by their phonological label is shown in Figure 6.2.

Although there is a difference between the voiced and the voiceless group this has more to do with the observation that fortis stops are invariably voiceless

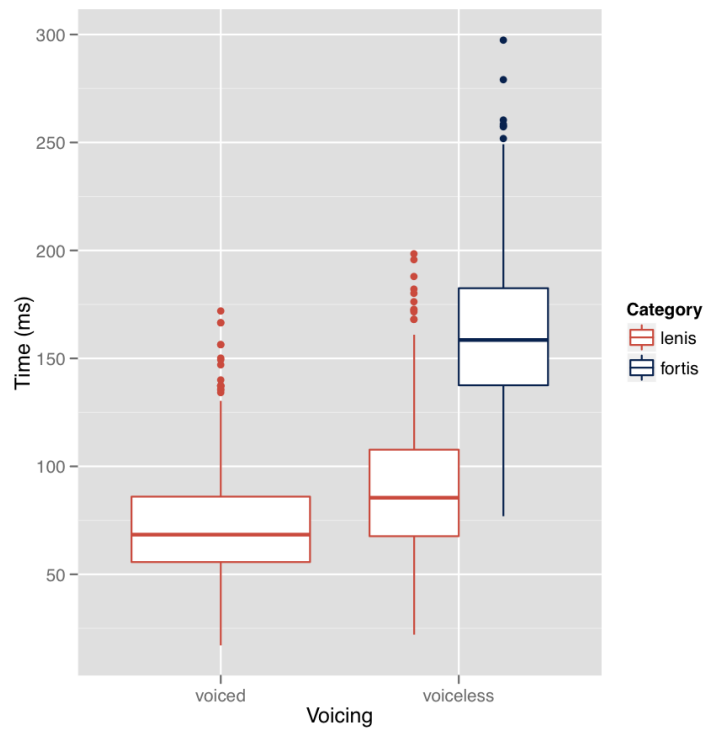


FIGURE 6.2: *The relative durations of lenis and fortis stops separated by voicing.*

and also have a long duration and lenis stop have a short duration but have variability in their voicing.

6.4.1 Place of articulation effects on stop duration within categories

Differences in place of articulation are known to affect duration of singleton consonants in other Australian languages , for example Yanyuwa (Bradley, 1980) and Goonayindi (McGregor, 1990). Bininj Gun-wok follows similar patterns in this regard with alveolars and retroflexes showing far more rapid articulator movement than bilabials and velars when not part of a cluster environment or realised as a fortis stop.

To investigate the effect of place of articulation within the lenis and the

fortis groups, each of the five places of articulation found in Biniŋj Gun-wok is presented individually for the fortis and lenis stop categories. The total stop duration is clearly different for the overall lenis and fortis groups.

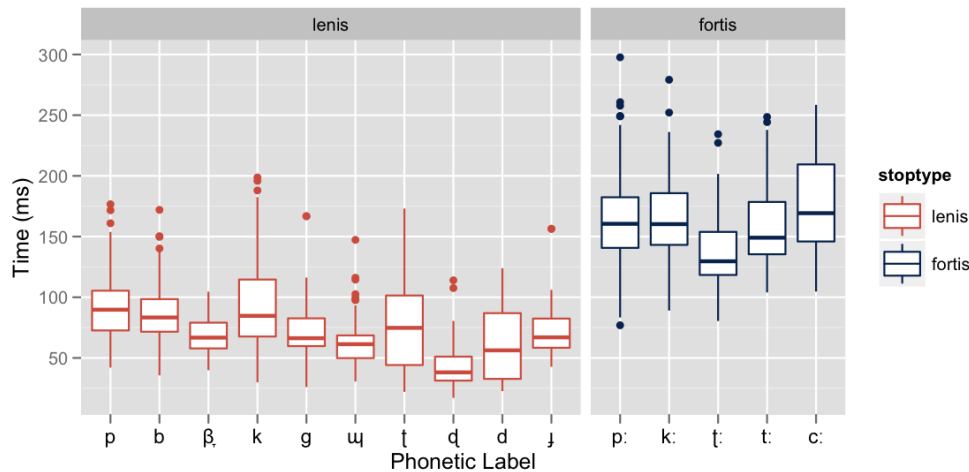


FIGURE 6.3: Stop durations for fortis medial stops separated by phonetic label for Corpus I and Corpus II pooled.

In broad terms, the fortis stops, [p: k: t: t:] and [c:] shown in the righthand panel of Figure 6.3 and the lenis stops, [p b β k g ŋ t ʈ ɖ c] and [ɟ] shown in the lefthand panel of Figure 6.3 clearly differ in terms of overall duration and this is confirmed statistically. The main effect of total consonant duration is significant based on the results of a LMEM which includes speaker identity and token (unique repetition of a word) as random factors and stop category as a fixed factor. A likelihood ratio test shows that the total duration of lenis and fortis stops are significantly different and consequently the null hypothesis is rejected ($\chi^2(5, N = 2461) = 754, p < .001$). The fortis stops are on average 53 ± 1.5 ms ($p < .001$) longer in duration than the lenis stops when the sample includes all speakers.

Figure 6.3 also shows the degree of variability present within the lenis group. Place of articulation differences will be discussed in more detail below

in reference to other measurements such as VOT and locus equations.

6.4.2 Total consonant duration: separated by speaker

The results of the earlier LMEM with stop category as a fixed factor and speaker as a random factor showed that there was indeed a difference between the two stop categories which was unaffected by speaker identity. To investigate any possible speaker specific effects, each speaker is considered individually in the following section. Individual ratios of lenis to fortis durations are reported. Table 6.4 shows a summary and the distribution of lenis and fortis stops in the sample, separated by speaker. The means have a range of just over 50 ms. The ratio of lenis to fortis stops have a variety of values but all have a ratio of just over 1:2 with the average ratio of also 1:2. As Table 6.4 shows, the sample sizes for each speaker are unequal and furthermore they are not balanced between lenis and fortis for each speaker or sample-wide. This imbalance is taken into account in the statistical measures chosen as a LMEM statistical tool is relatively robust when handling missing values.

TABLE 6.4: Number (n), mean duration ($\bar{x}$), median duration ($\tilde{x}$) and standard deviation (σ) of fortis and lenis stop durations, separated by speaker for the both corpora (I and II)—all measurements in milliseconds (ms).

SPEAKER	FORTIS				LENIS				RATIO (lenis:fortis)
	n	$\bar{x}$	$\tilde{x}$	σ	n	$\bar{x}$	$\tilde{x}$	σ	
AB	15	185	187	29	21	59	59	19	1:3.12
BN	72	172	166	25	42	69	67	25	1:2.48
CJ	63	187	191	28	25	96	99	25	1:1.95
CL	43	167	161	30	19	81	76	20	1:2.06
CM	227	160	158	22	80	73	68	23	1:2.19
DD	37	138	145	20	16	74	75	6	1:1.85
DJ	20	164	163	17	15	85	82	22	1:1.91
DN	98	151	152	24	152	61	59	25	1:2.47
HK	91	121	120	19	166	66	64	20	1:1.83
JM	102	165	167	27	144	74	70	26	1:2.23
MM	89	209	211	24	133	101	96	33	1:2.07
MN	24	168	168	18	29	93	93	18	1:1.8
OK	92	144	138	31	149	71	72	25	1:2.03
RN	84	184	182	35	44	96	96	30	1:1.92
TD	92	142	141	21	58	83	84	26	1:1.7
VB	44	195	191	29	26	102	97	29	1:1.91

The mean duration of lenis and fortis stops is marginally significantly different for all speakers ($p > .001$ but significant at $p < 0.05$ above the α level for this study, however.) but importantly, this is not separating by place of articulation. These results only suggest that duration constitutes a consistent phonetic difference between the two stop series for all speakers.

A subset of speakers, DN, HK, OK, JM and MM (Corpus I) are analysed at all places of articulation. The results are shown in Tables 6.5, 6.6, 6.7, 6.8 and 6.9 and also in Figure 6.4 which shows a summary of all of the durations separated by place of articulation.

TABLE 6.5: *Summary for speaker DN, number (n), mean duration ($\bar{x}$), median duration ($\tilde{x}$) and standard deviation (σ) of fortis and lenis stops, all measurements in milliseconds (ms) (Corpus I).*

	<i>n</i> .FORTIS	$\bar{x}$.FORTIS	$\tilde{x}$.FORTIS	σ .FORTIS	<i>n</i> .LENIS	$\bar{x}$.LENIS	$\tilde{x}$.LENIS	σ .LENIS	RATIO
TOTAL	98	151	152	24	152	61	59	25	1:2.47
BILABIAL	30	157	157	25	62	70	65	24	1:2.23
VELAR	28	159	159	25	60	66	62	22	1:2.4
PALATAL	9	163	160	15	2	53	53	0	1:3.05
ALVEOLAR	17	146	144	16	5	33	32	7	1:4.44
RETROFLEX	14	124	123	10	23	30	32	7	1:4.02

TABLE 6.6: *Summary for speaker HK, number (n), mean duration ($\bar{x}$), median duration ($\tilde{x}$) and standard deviation (σ) of fortis and lenis stops, all measurements in milliseconds (ms) (Corpus I).*

	<i>n</i> .FORTIS	$\bar{x}$.FORTIS	$\tilde{x}$.FORTIS	σ .FORTIS	<i>n</i> .LENIS	$\bar{x}$.LENIS	$\tilde{x}$.LENIS	σ .LENIS	RATIO
TOTAL	91	121	120	19	166	66	64	20	1:1.83
BILABIAL	29	119	121	17	62	70	70	14	1:1.7
VELAR	27	133	131	18	54	62	61	21	1:2.15
PALATAL	9	117	114	11	14	67	67	16	1:1.74
ALVEOLAR	17	119	119	9	8	76	82	22	1:1.57
RETROFLEX	9	93	88	13	28	60	52	27	1:1.55

There do not seem to be any consistent differences in duration based solely on place of articulation. Place of articulation will be considered for this sample in more detail below when looking at VOT, VTT and coarticulatory effects between intervocalic stops and surrounding vowels (see § 6.5 and § 6.8).

TABLE 6.7: Summary for speaker OK, number (n), mean duration ($\bar{x}$), median duration ($\tilde{x}$) and standard deviation (σ) of fortis and lenis stops, all measurements in milliseconds (ms) (Corpus I).

	n .FORTIS	$\bar{x}$.FORTIS	$\tilde{x}$.FORTIS	σ .FORTIS	n .LENIS	$\bar{x}$.LENIS	$\tilde{x}$.LENIS	σ .LENIS	RATIO
TOTAL	92	144	138	31	149	71	72	25	1:2.03
BILABIAL	30	135	126	26	63	76	74	18	1:1.78
VELAR	28	142	140	26	59	75	74	25	1:1.89
PALATAL	9	201	209	21	2	71	71	7	1:2.82
ALVEOLAR	17	143	138	22	0				1:NaN
RETROFLEX	8	122	127	13	25	49	33	27	1:2.49

TABLE 6.8: Summary for speaker JM, number (n), mean duration ($\bar{x}$), median duration ($\tilde{x}$) and standard deviation (σ) of fortis and lenis stops, all measurements in milliseconds (ms) (Corpus I).

	n .FORTIS	$\bar{x}$.FORTIS	$\tilde{x}$.FORTIS	σ .FORTIS	n .LENIS	$\bar{x}$.LENIS	$\tilde{x}$.LENIS	σ .LENIS	RATIO
TOTAL	102	165	167	27	144	74	70	26	1:2.23
BILABIAL	30	158	160	22	62	84	84	19	1:1.86
VELAR	31	184	187	20	33	78	70	35	1:2.35
PALATAL	9	179	178	18	17	68	66	12	1:2.63
ALVEOLAR	17	167	167	22	10	48	40	18	1:3.45
RETROFLEX	15	130	126	16	22	54	51	21	1:2.4

TABLE 6.9: Summary for speaker MM, number (n), mean duration ($\bar{x}$), median duration ($\tilde{x}$) and standard deviation (σ) of fortis and lenis stops, all measurements in milliseconds (ms) (Corpus I).

	n .FORTIS	$\bar{x}$.FORTIS	$\tilde{x}$.FORTIS	σ .FORTIS	n .LENIS	$\bar{x}$.LENIS	$\tilde{x}$.LENIS	σ .LENIS	RATIO
TOTAL	89	209	211	24	133	101	96	33	1:2.07
BILABIAL	26	205	207	20	63	101	96	26	1:2.02
VELAR	27	210	211	25	53	107	104	33	1:1.96
PALATAL	9	231	226	17	0				1:NaN
ALVEOLAR	14	220	219	16	0				1:NaN
RETROFLEX	13	187	185	24	17	80	67	44	1:2.34



FIGURE 6.4: Mean consonant duration of medial stops separated by stop type (Corpus I).

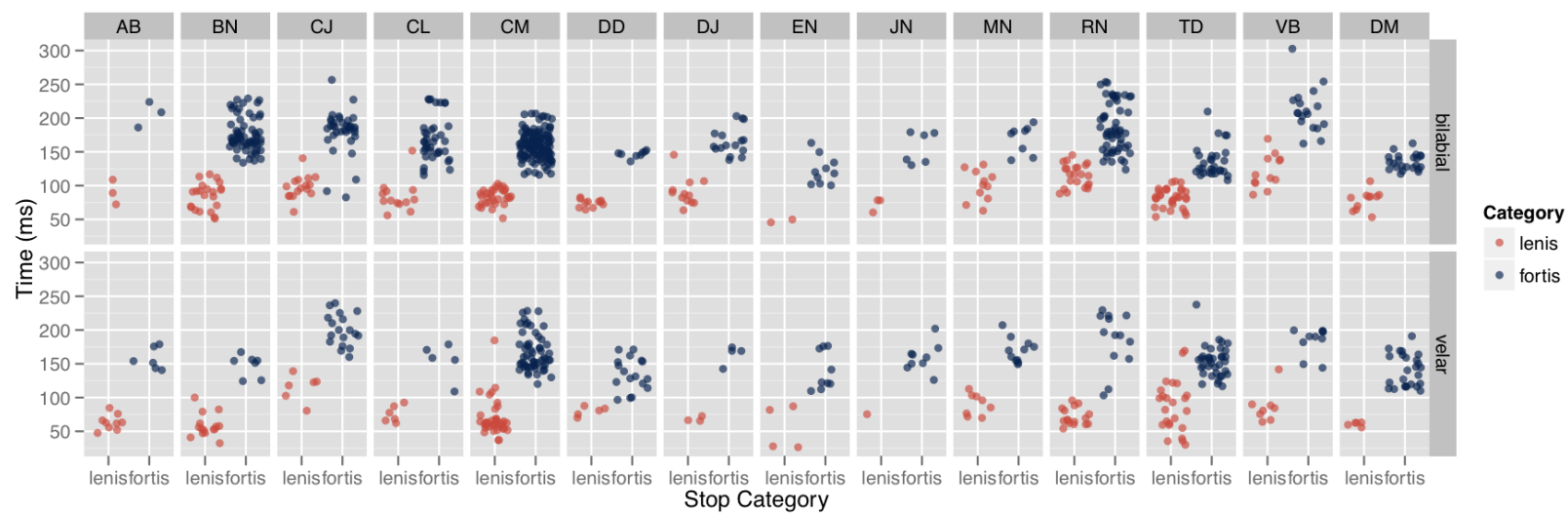


FIGURE 6.5: Mean consonant duration of medial stops separated by stop type (Corpus II).

When each speaker is analysed individually (shown in Figure 6.4), speaker HK shows less variation between the duration of lenis and fortis stops. The ratios for this speaker at each place of articulation (reported in Table 6.6) show that the ratio of lenis to fortis stop duration is similar to that of other speakers. There is overlap between the lenis and fortis categories particularly amongst the peripheral category. Only the peripherals have been reported for Corpus II due to the small sample size at other places of articulation for the majority of speakers. Figure 6.5 shows for speaker TD there is greater separation in the duration of medial bilabial stops when compared with velars.

Examining each corpus individually, similar patterns are to be found. In Corpus I an LMEM is calculated with using stop category as the fixed factor and speaker, word, and year of recording as random factors. The main effect of consonant duration is significant between the categories and a likelihood ratio test gives a statistically significant result ($\chi^2(5, N = 1216) = 289, p < .001$). The fortis stops are 54 ± 2 ms longer in duration than the lenis stops ($p < .001$) calculated using a Tukey HSD.

In Corpus II a similar LMEM is calculated including the same set of fixed and random factors. The likelihood ratio test shows a statistically significant result ($\chi^2(8, N = 1245) = 512, p < .001$) when testing a main effect of stop category on consonant duration. The fortis stops are on average 54 ± 2 ms longer than the lenis stops ($p < .001$).

These results show that there are clear differences between the lenis and fortis stops based on their duration. What is less clear from these plots and the statistical tests however, is the extent that place of articulation effects the duration. It also fails to show the inter-speaker variation. These variables will be explored further in the following sections.

6.5 Stop structure: voice termination time, occlusion and voice onset time

Total duration is not the only difference evident. The two stop categories are not uniform in their realisations and lenis and fortis stops are different in a number of other respects. In this section the results of VTT, cessation of voicing during stop occlusion (-ve voice) and VOT are presented as well as overall duration (see Table 6.10). There are a number of different possible realisations that will be presented prior to the quantitative analysis. This presents some of the possible realisations of stops regardless of their phonological label. See § 5.6.5 and § 5.6.4 for more information on labelling and data included in this analysis.

TABLE 6.10: *Summary of Stop types in Bininj Gun-wok combining VTT, cessation of voicing and VOT.*

TYPE	VTT	-VE VOICE	VOT
TYPE 1	+	+	+
TYPE 2	+	+	-
TYPE 3	+	-	-
TYPE 4	-	+	+
TYPE 5	+	-	+

The stop types can be summarised as one of five possible types.

- Type 1—consists of a positive VTT followed by a period of voicelessness which ends by the burst and a positive voice onset time
- Type 2—also has a positive VTT and a period of voicelessness but a release coincident with the onset of the vowel (under 5 ms) and consequently a virtually coincident VOT
- Type 3—displays voicing that continues throughout the stop a coincident VOT—there is no obvious burst in this stop type.

- Type 4—displays virtually no VTT time (under 5 ms) with a period of voicelessness and a positive VOT.
- Type 5—displays voicing that continues until the burst and then a period of time between the release and the vowel (usually devoiced but sometimes voiced).

Other possible combinations of these parameters are not attested to occur in these data. The quantitative analyses of VOT and VTT are presented below in § 6.5.1 and § 6.5.3.

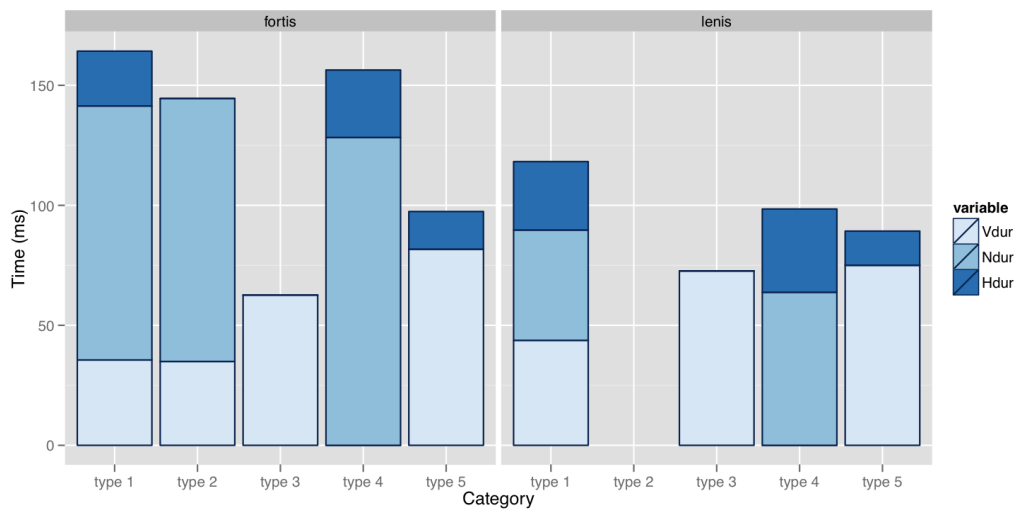


FIGURE 6.6: *Different internal structures found in lenis and fortis stops separated by category as defined in Table 6.10.*

In Figure 6.6, *Vdur* refers to VTT, *Ndur* is the period of occlusion for which there is no voicing and *Hdur* is the VOT. Type 3 and type 5 seem identical in structure and duration for both lenis and fortis phonological categories, yet only one fortis token is of type 3 and ten fortis token of type 5 in the entire corpus (shown in Table 6.11). These may be examples of mis-categorised lenis stops—either due to mislabelling or an error of analysis. Fortis stops are most likely to be realised as either type 1 or type 4 and lenis stops are most likely to be realised as type 3 or type 5, indicating they are fully voiced throughout and

are found with or without a burst (see Table 6.12). Type 2 is underrepresented in the sample and only occurs in fortis articulations.

TABLE 6.11: *Distribution of stop category by stop composition (type).*

TYPE:	LENIS <i>n</i>	FORTIS <i>n</i>
TYPE 1:	26	668
TYPE 2:	0	20
TYPE 3:	192	1
TYPE 4:	13	118
TYPE 5:	137	10

The duration of the VTT is different based on the stop category. This may indicate that differing strategies are used for voicing in each of the stop categories. Place of articulation differences may also affect the presence or absence of VTT. As discussed in § 2.4.2, VTT duration is greater in articulations that have a larger resonant cavity behind the closure such as bilabial stops. This is due to the likelihood of cavity expansion at this place of articulation. The velar place of articulation, due to its posterior closure, has less expandable tissue. Consequently there is less passive expansion of the vocal tract leading to prolonged voicing. The durations of VTT are in excess of those expected in articulations with no active prolongation of voicing (approximately 5 ms to 10 ms according to Ohala and Riordan (1979)).

The release characteristics of medial stops show that fortis stops are more likely to have a clear burst than lenis stops with 96% of fortis stops having a identifiable burst, but only 45% of lenis stop closures containing a burst. Clear bursts are defined as containing a transient that excites a wide frequency range (see § 5.6.8). In contrast, the lenis stops are marginally more likely (55%) to be fully voiced throughout the close and lack a defined burst at the closure release. Many lenis fully voiced stops, however, also have a clear release burst at all places of articulation. Each place of articulation is analysed separately

below in § 6.7.1. Only four fortis stops lack a defined burst at the release of closure and it is possible that a weak burst will be masked by coincident voicing at the vowel onset. A summary of the release characteristics of stops is shown in Table 6.12.

TABLE 6.12: *Presence and absence of clear release bursts in lenis and fortis stops found in Corpus II (Frequency).*

	BURST	NO BURST
FORTIS	812	32
LENIS	182	219

The incidence of clear bursts in lenis stops are far more variable than for those in fortis stops (see Table 6.12). Lenis stops without a clear burst may be fully voiced, devoiced or both (see previous section above).

The place of articulation effects that influence differences in VTT and VOT are investigated below in the next section and § 6.5.3 where speaker specific effects are investigated.

6.5.1 Voice onset time

Table 6.13 presents a summary of VOTs in Biniŋ Gun-wok from 10 speakers in Corpus II. This table shows that palatal fortis stops have the longest VOT followed by velar and bilabial fortis stops. Alveolar and retroflex fortis stops have the shortest VOT with exceptionally short durations which by most definitions would be considered coincident. The stops in the lenis category all have a negative mean VOT, indicating that the stops are fully voiced throughout the closure and that voicing has initiated or has been preserved prior to the release of the articulators. Within the lenis stop category the bilabial stops show the longest negative VOT followed by alveolar, velar, retroflex with palatals with the shortest negative VOT. Comparing these results to those found by Cho and Ladefoged (1999, p. 219) at all places of articulation the fortis stops have par-

ticularly short VOT values and each place of articulation will be investigated below.

TABLE 6.13: *Summary of mean VOTs (ms) in lenis and fortis medial stops for ten speakers in Corpus II.*

	bilabial	velar	palatal	alveolar	retroflex
FORTIS	20	23	34	15	17
LENIS	-75	-54	-2	-67	-47

The box plots shown in Figure 6.7, Figure 6.8 and Figure 6.9, shows the positive VOTs for all speakers in the study. There is a high degree of variation due to pooling all speakers. Figure 6.8 shows the positive VOTs in Corpus II and Figure 6.9 shows the negative VOTs for Corpus II.

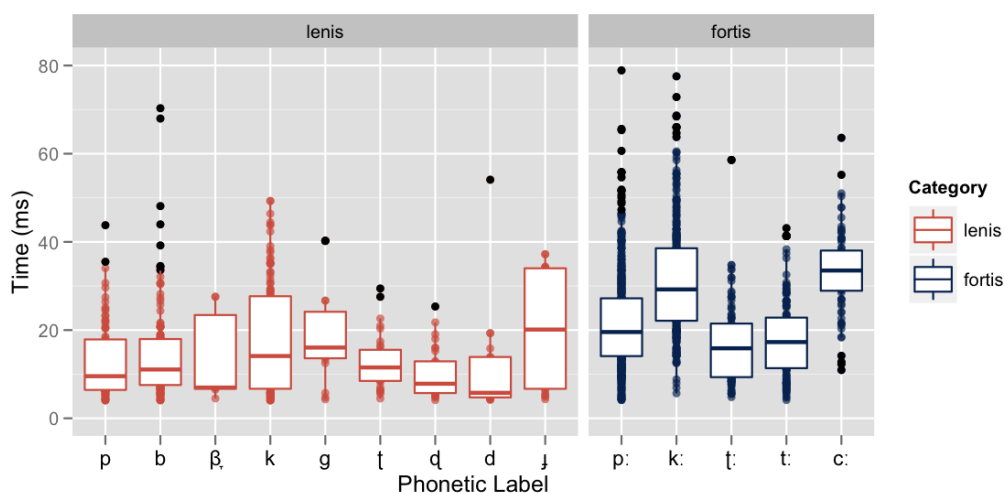


FIGURE 6.7: *Positive Voice onset times pooled for the entire corpus.*

The five places of articulation are each plotted separately, with the exception of the retroflex stops as there were insufficient tokens in Corpus II to summarise them graphically. Within the sample there are far fewer palatal, alveolar and retroflex stops than bilabial and velar stops. The coronal consonants are by far the most interesting articulations from a typological point of view and it

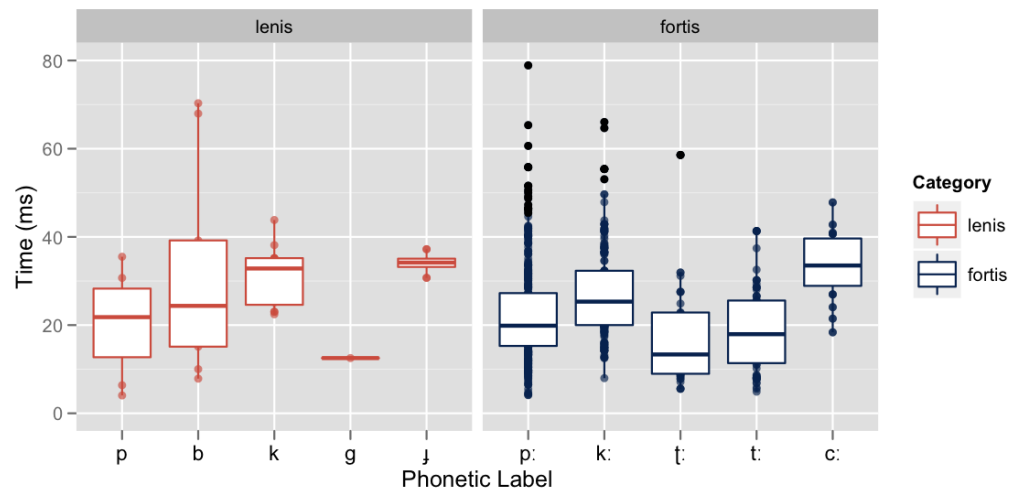


FIGURE 6.8: Positive Voice onset times separated by phonetic label for Corpus II.

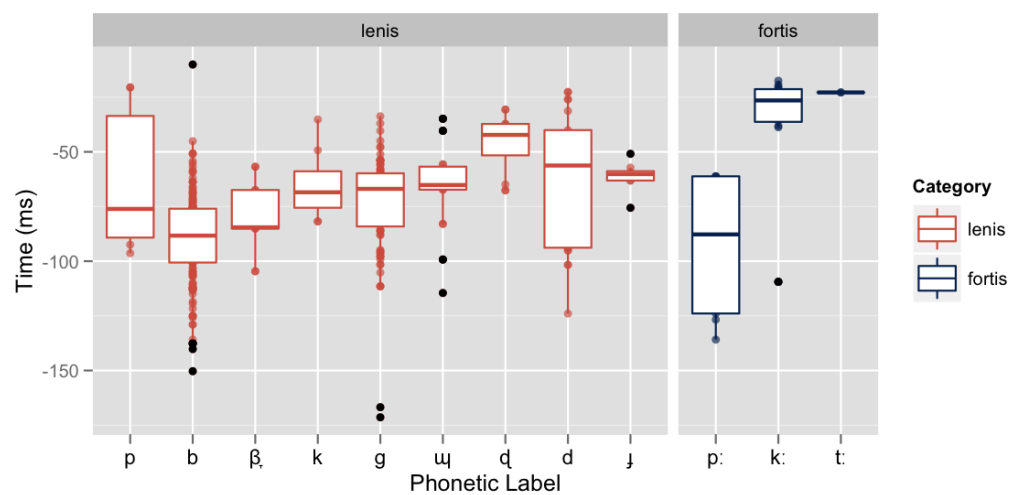


FIGURE 6.9: Negative Voice onset times separated by phonetic label for Corpus II.

is for this reason that they are included in the analysis despite the small sample size.

For all of the following measurements, the seemingly obligatory positive VOT in the fortis stops indicates no voicing or partial voicing. The negative VOT that is common for the lenis stops indicates voicing throughout the closure. If voicing ceases for any time during the closure, the VOT is considered positive. In the following figures (bilabials shown in Figure 6.10, velars in Figure 6.11, palatals in Figure 6.12 and alveolars Figure 6.13) the time corresponding with the point of closure release is marked with a vertical dashed line and a zero on the x-axis. Negative values (to the left of the line) correspond with negative VOTs and positive values (to the right of the line) correspond to positive VOTs. The values on the y-axis show the percentage of the total sample each bar represents.

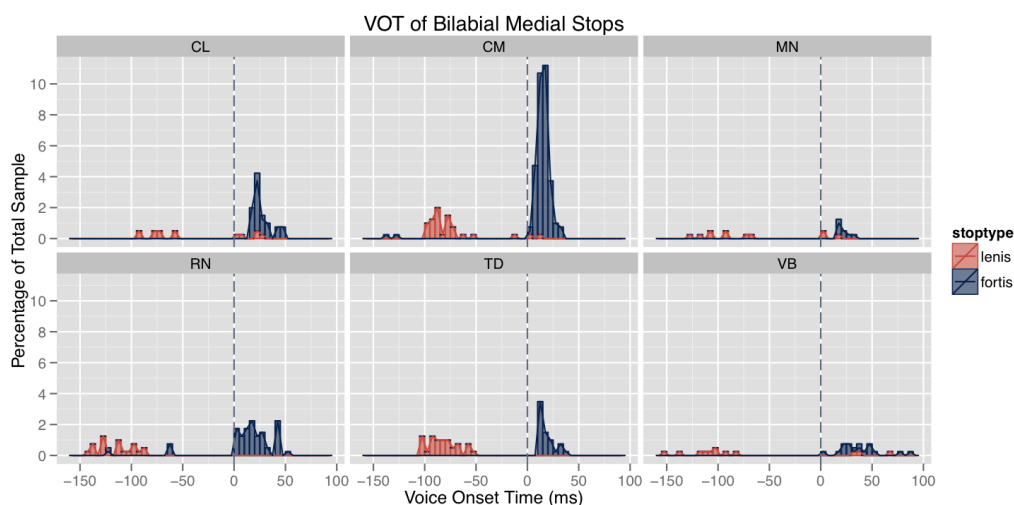


FIGURE 6.10: Voice onset times medial bilabial stops separated by speaker, Corpus II.

The results for the VOT in bilabial medial stops are shown in Figure 6.10. Each speaker is plotted in a separate panel and the voice onset times are presented as histograms that show them as a percentage of the entire sample. It is clear that the VOT values differ depending on the speaker.

There is greater variation in the lenis VOTs, for all speakers. The distribu-

tion of VOT values in lenis stops shows a weakly bimodal pattern with one mode registering negative VOTs and the second mode with positive VOTs. When the two groups within the lenis tokens are separated dependent on whether the VOT is positive or negative, the negative VOTs have a mean VOT of -86 ms ($\sigma = 29$). The small group with positive VOTs have a mean duration of 18 ms ($\sigma = 51$). The positive VOTs are very short when considered cross-linguistically. The lenis stops with positive VOTs have similar VOTs to the fortis stops. The fortis stops predominantly show positive VOT values. This is perhaps an indication that place of articulation and voicing both have an influence on the VOT. As discussed above, the majority of lenis stops with a positive VOT, which are also voiceless, have release characteristics that are more comparable to fortis stops than to the remaining lenis stops.

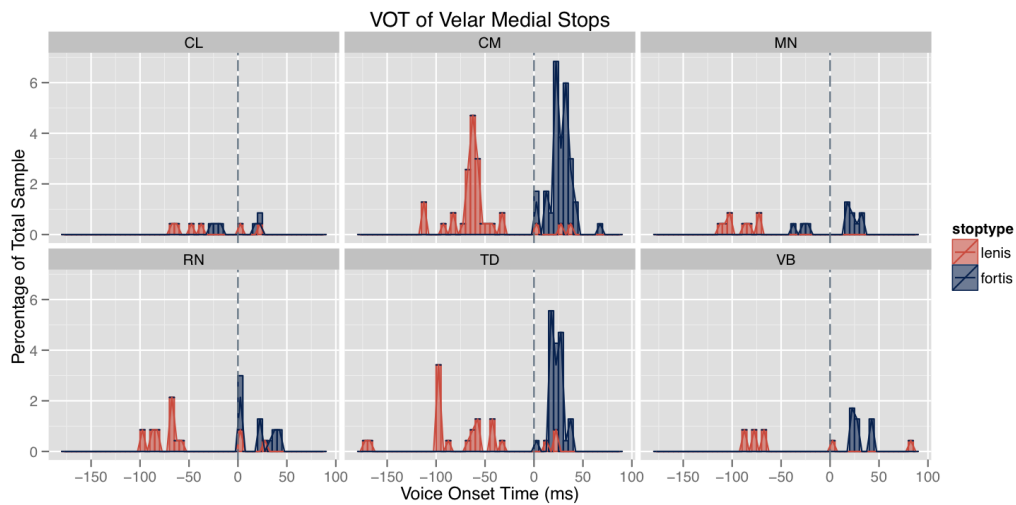


FIGURE 6.11: Voice onset times medial velar stops separated by speaker, *Corpus II*.

The results of VOT measurements in lenis and fortis velar stops are shown in Figure 6.11. Each speaker is plotted separately as above.

Just as in the bilabial stops the density plots show that the VOT measurements are weakly bimodal. The lenis stops generally show negative VOTs and within this group those tokens that show negative VOTs have a mean of -64 ms ($\sigma = 31$) and those tokens with positive VOTs have a mean of 18 ms ($\sigma = 31$).

As shown in the results of previous cross-linguistic research on velar stops, the average VOT is longer in the velar fortis stops than for the bilabial fortis stops.

A bimodal pattern is not observed in the VOT values of palatal stops (see Figure 6.12). This is due to the small sample size at this POA. There were only two lexical items, one lenis and one fortis. Consequently this does not give an accurate representation of what is occurring within the lenis category. Despite this, these results are reported.

Within the lenis stop category the stops with negative VOT values have a mean VOT of -61 ms and those tokens with positive VOTs have a mean of 34 ms. As previously noted in Chapter 4, palatal stops show significant friction in the release phase which is due to the relatively high surface area of the primary articulator and the large closure area. Within the fortis palatal stops, the mean VOT duration is 34 ms ($\sigma = 8$). In the majority of Australian languages, including Bininj Gun-wok, palatal stops are more properly described as alveo-palatal stops rather than lamino-palatal, indicating that the tongue is slightly more anterior (see § 1.3).

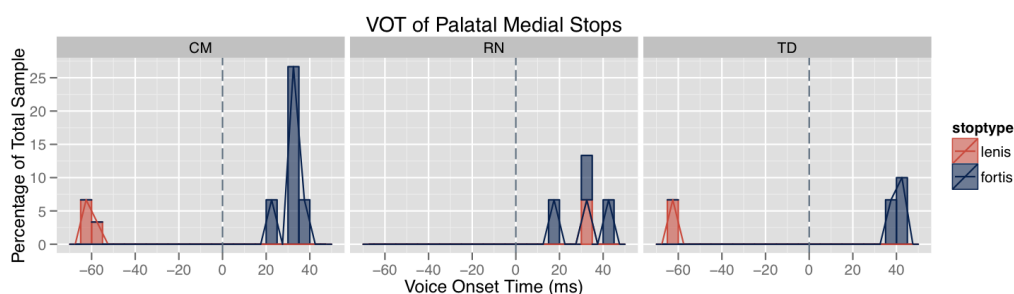


FIGURE 6.12: Voice onset times medial palatal stops separated by speaker, *Corpus II*.

There are significantly fewer apico-alveolar lenis stop tokens in the corpus ($n=17$). As the sample of apico-alveolar is relatively small it is not possible to tell if the distribution is bimodal in lenis stops, as at the other places of articulation. By way of comparison the mean for the lenis alveolar stops is -67 ms and the mean for the fortis alveolar stops is 18 ms.

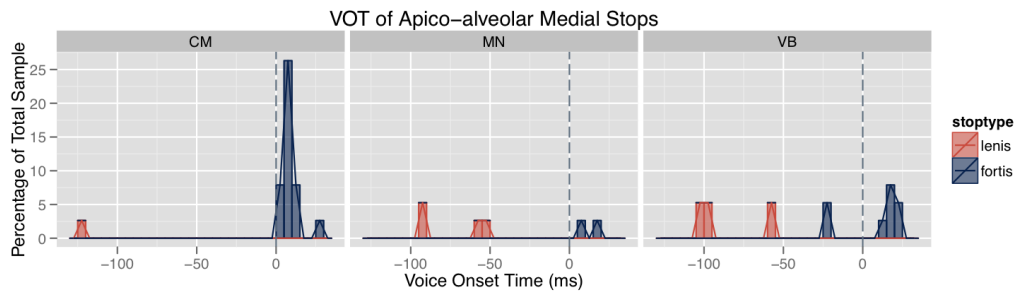


FIGURE 6.13: Voice onset times medial apico-alveolar stops separated by speaker, Corpus II.

In general when the analysis is restricted to positive VOT values they differ depending on the place of articulation. VOT does not differ as a function of stop category (lenis or fortis). The negative VOT values are predominantly found in lenis fully voiced stops and the voicing has carried on throughout the closure rather than voicing being initiated. The negative VOT values seem to be largely independent of place of articulation effects.

There is greater variation in the VOT of lenis stops whereas the fortis stops show great stability with a positive VOT in almost all tokens. This variation found within the lenis stops can be explained by passive devoicing whereas the fortis series shows active devoicing. The bimodal patterning is interesting because the mode that is greater than zero is very similar in value to the mode for the fortis stop at the corresponding place of articulation. Of course more data are needed to fully investigate this—for example within the alveolar stops—but qualitatively this hypothesis seems to stand up under quantitative scrutiny.

The results of a LMEM ($\chi^2(8, N = 1245) = 46.1, p < .001$) testing a main effect of VOT including *place of articulation* as a fixed factor and *speaker* and *token* as random factors, shows that the VOTs of bilabial stops are not significantly different to the VOTs of velar stops. Both bilabial stops and velar stops are significantly different in VOT to the coronal stops (apico-alveolar,

retroflex and palatal). Using a Tukey HSD to test the interactions, the bilabials differ from palatals by 58 ± 12 ms ($p < .001$), from alveolars by 48 ± 9 ms ($p < .001$) and from retroflexes by 42 ± 12 ms ($p < .001$).

Overall, testing a main effect of VOT with stop category as a fixed factor and the same random factors as the previous test, the two groups are statistically different. A likelihood ratio test ($\chi^2(5, N = 1245) = 472, p < .001$) shows to be significant and *post hoc* tests show that lenis and fortis stops differ by a mean duration of 55 ± 2 ms ($p < .001$).

As noted by Abramson (1977, p. 296), within the languages reported by Lisker and Abramson (1964) there is a trimodal distribution of VOTs. These three modes broadly have their median at -100 ms for fully voiced stops, +10 ms for voiceless stops and +75 ms for aspirated stops (Lisker & Abramson, 1964, p. 403). In Biniñ Gun-wok the distribution of VOTs in word medial stops is also a generally trimodal distribution with negative, coincident and positive VOT values observed, particularly within the peripheral class. The majority of the medial lenis stops however, fit a bimodal distribution. This is due to the realisation of lenis stops as both fully voiced and voiceless unaspirated stops. The fortis stops on the other hand have a unimodal distribution of VOTs at all places of articulation. This reflects the fact that fortis stops are almost invariably realised as voiceless and unaspirated. There are a very small number of tokens that have VOTs patterning with the alternate stop category. This is only evident for a small subset of speakers however.

6.5.2 Voice onset time of initial stops

By way of a comparison the VOTs of initial stops are reported in the following figures (Figures 6.14 and 6.15). The initial VOTs show a trimodal distribution in the peripheral class of stops, with negative VOTs, coincident VOTs and positive VOTs.

There are no examples of initial retroflex stops in Figure 6.15, as the contrast

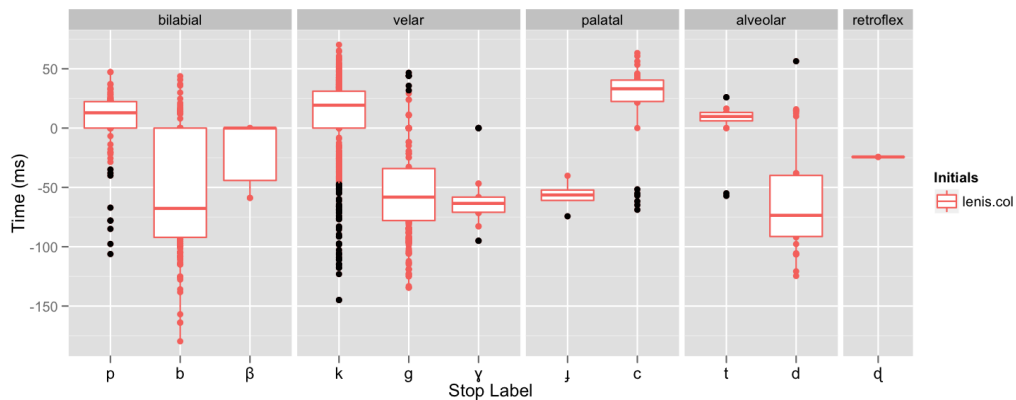


FIGURE 6.14: Summary of the voice onset times for initial stops stops, Corpus II.

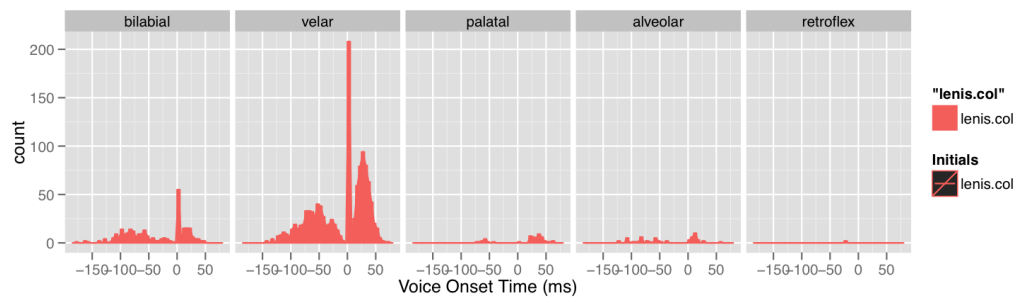


FIGURE 6.15: Voice onset times of initial stops by place of articulation, Corpus II.

is phonologically neutralised in initial position (see § 4.4.2).

A statistical analysis using a LMEM ($\chi^2(8, N = 1245) = 42.4, p < .001$), shows the main effect of VOT is based on place of articulation (fixed factor) and including speaker and token as random factors. This does not hold for all places of articulation possibly due to the uneven sample sizes. The VOT of the velars is significantly different to the bilabials and the palatals. The VOT of the bilabials is significantly different to the velars and the palatals and the VOT of the palatals is significantly different to the alveolars. In summary, VOT is different dependent on place of articulation, regardless of the position within the word.

6.5.3 Voice termination time

If both lenis and fortis stops are passively devoiced or are devoiced using the same voicing strategy, as expected the VTT is similar for both lenis and fortis stops. The results of a durational analysis of VTT are shown below.

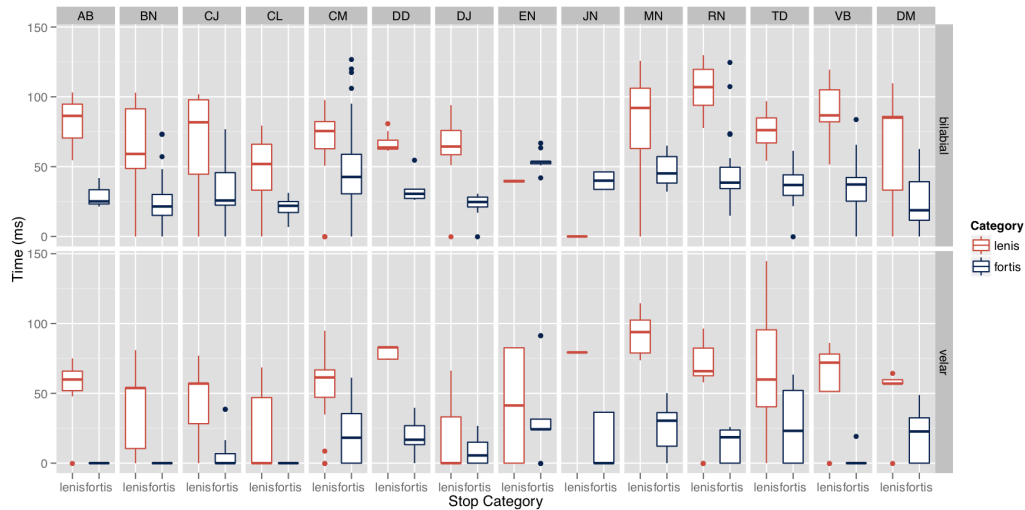


FIGURE 6.16: *Voice termination time.*

Voice termination time varies dependent on stop category. VTT also changes dependent on place of articulation. The LMEM ($\chi^2(5, N = 1245) = 135$, $p < .001$), shows that differences in VTT are significant based on a stop category as a fixed factor and speaker and token as random factors. The VTT in fortis stops 22 ± 2 ms ($p < 0.001$) is shorter in duration than that of the lenis stops. These are very short differences that are possibly too short to be perceptible however. When both place of articulation and stop category are included as fixed effects—again including speaker and token as random effects—only the bilabial and velars have VTT that are significantly different to each other ($p = .001$). The differences are consistent however and they suggest that there are different laryngeal articulations at the consonant onset although these may be too short for a listener to perceive acoustically.

6.6 Vowel duration

As shown above in § 6.4, lenis stops are usually produced with voicing that extends through the majority of the consonant closure. Fortis stops have short periods of glottal pulsing described as a short VTT. It has been shown in other languages that a vowel preceding a voiced stop is often longer than a vowel preceding a voiceless consonant. The durations of vowels are measured in this section.

The durations of vowels preceding stops are shown in Figure 6.17 and Figure 6.18, which generally shows that the vowels preceding the consonant (V_1) are more variable before lenis stops.

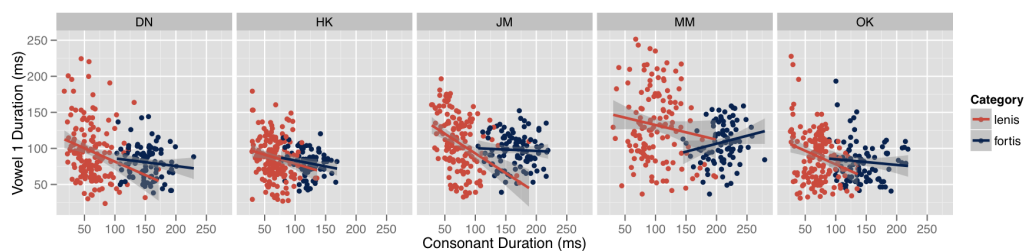


FIGURE 6.17: The duration of vowels preceding fortis and lenis medial stops by speaker in *Corpus.I*.

Figure 6.17 shows the V_1 duration before medial stops in *Corpus I*. When the duration data for all speakers are pooled, the vowels preceding fortis stops have a lower mean duration at 90 ms than vowels preceding lenis stops which have a mean duration of 101 ms. The LMEM finds the groups are not significantly different for a main effect of preceding vowel duration (V_1 duration) in *Corpus I*, with speaker included as a random effect.

Figure 6.18 shows the duration of vowels preceding stops in *Corpus II*. The vowels preceding fortis stops have a lower mean duration (88 ms) compared with the V_1 preceding lenis stops (127 ms) for all speakers.

For *Corpus II*, the LMEM shows a significant main effect of preceding vowel duration with a fixed factor of stop category and speaker and token included

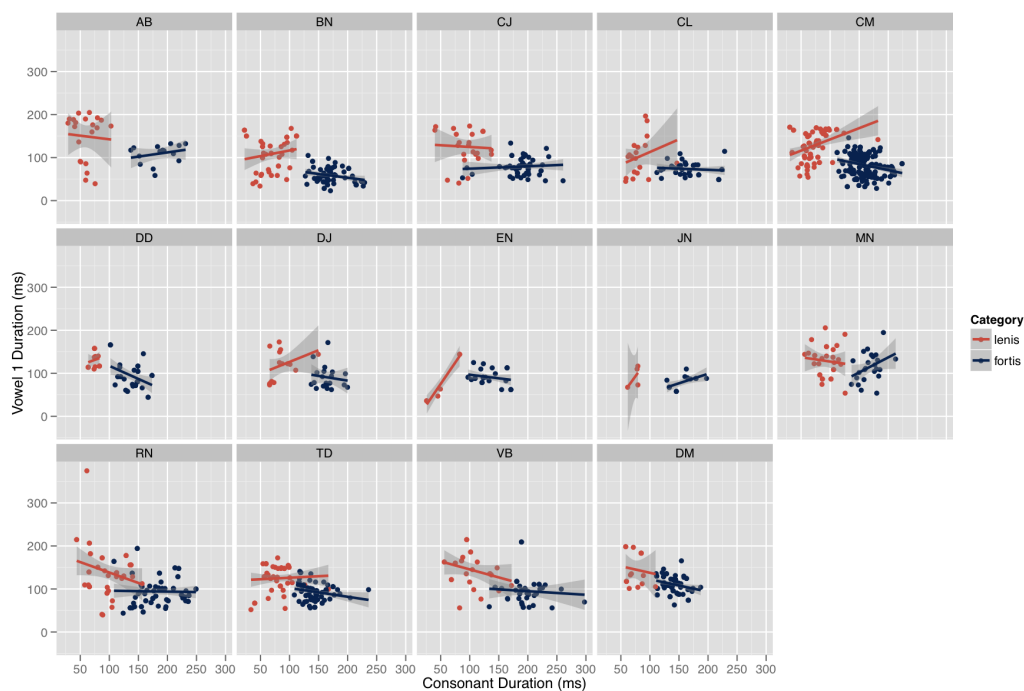


FIGURE 6.18: *The duration of vowels preceding fortis and lenis medial stops by speaker in Corpus.II.*

as random factors ($\chi^2(5, N = 1245) = 31, p < .001$). Subsequent test show that the vowels that precede fortis stops are 12 ± 2 ms ($p < .001$) shorter than those that precede lenis stops. This difference in durations is very small however and possibly too short to be acoustically perceptible to the listener.

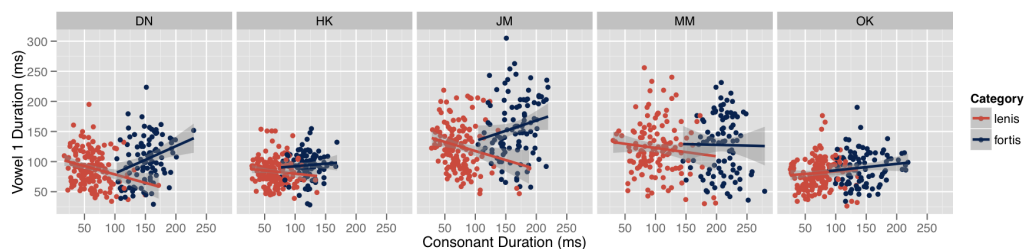


FIGURE 6.19: *The duration of vowels following fortis and lenis medial stops, Corpus I.*

The vowels that follow both fortis and lenis stops do not show this same pattern however, (see Figures 6.19 and 6.20 which compares V_2 duration with

consonant duration). For the speakers in Corpus I, a LMEM shows a main effect of V_2 duration when stop category (fixed factor) and speaker and token (random factors) are included. The results of the likelihood ratio show that the null hypothesis cannot be rejected ($\chi^2(5, N = 1245) = 2.34, p = .13$). This suggests that there is no significant difference in the duration of vowels (V_2) following lenis and fortis stops.

When all speakers are pooled together, the vowels following fortis stops have a higher mean duration at 115 ms when compared with vowels following lenis stops, which have a mean duration of 99 ms.

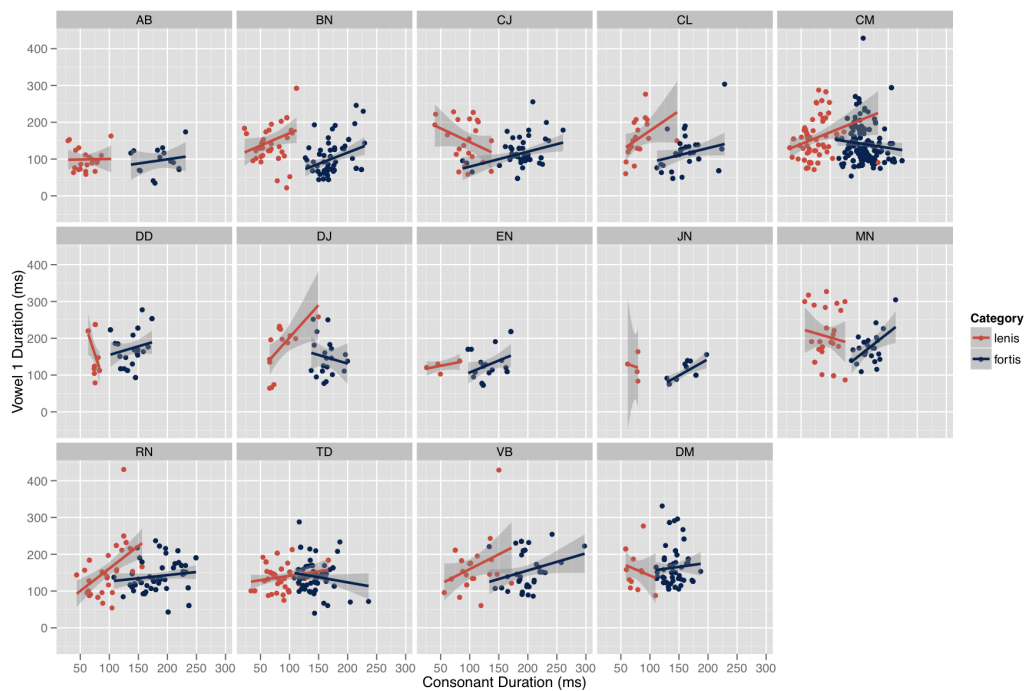


FIGURE 6.20: The duration of vowels following fortis and lenis medial stops, Corpus II.

Figure 6.20 shows the duration of vowels following stops in Corpus II compared with the consonant duration. The vowels following fortis stops do not have a significantly different mean duration at 137 ms than vowels following lenis stops which have a slightly higher mean duration of 153 ms, for all speakers.

From these data, the duration of the preceding vowel (V_1) is shown to be

shorter preceding fortis stops than preceding lenis stops. This effect is reversed for the following vowel (V_2) with a fortis stop showing a longer vowel and a lenis stop a shorter vowel. There is no control of the other consonants within the words and consequently there may be other long range coarticulatory effects that are dependent on the place of articulation of stops not included in the analysis.

These data suggest that medial consonants exerts a greater influence over the preceding vowel than over the following vowel, but as they are not consistently statistically significant this may be evidence of pre-fortis clipping. See § 2.1.2 for discussion of the universal nature of vowel shortening before voiceless stops. A more controlled experiment needs to be constructed however, to confirm that vowel shortening effects are of statistical significance. This may suggest that fortis stops are in the coda position of syllables (see § 1.3.2 for a discussion of syllable structure in Bininj Gun-wok).

6.7 Results: an analysis of the burst

The following sections now turn the attention away from durational effects and examine some of the non-temporal differences between lenis and fortis stops. The release burst of consonants contains important place of articulation cues and in addition may signal differences in articulatory strength both in terms of loudness and spectral characteristics. Amplitude differences at the burst are considered to be a potential cue to phonetic differences between lenis and fortis stops. In addition to absolute amplitude, the relative amplitude of the entire consonant compared with the following vowel in both lenis and fortis stops is measured.

6.7.1 Burst amplitude

The burst of a consonant is a high energy transient peak that occurs at the release of the articulators which is particularly salient in oral stops. The following plots show the average RMS amplitude for a 20 ms window centered around the release burst of lenis and fortis stops.

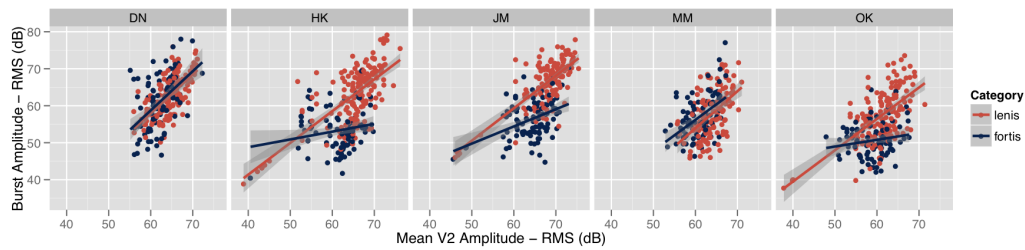


FIGURE 6.21: The mean amplitude of V_2 compared with the mean burst amplitude (RMS amplitude measured in dB).

Figure 6.21 shows the mean values which form the basis of the Δ_{amp} measurement. This is the difference in RMS amplitude of burst compared with that of the following vowel. When testing Δ_{amp} with a main effect of stop category ($\chi^2(5, N = 1245) = 27.4, p < .001$) the difference between them is significant ($p > .001$). The average difference in RMS amplitude between the burst of a fortis stop and the mean difference of amplitude the burst compared with the mean amplitude of the following vowel is 6 dB whereas for a lenis stop the mean difference is 3 dB. This indicates that the release of a lenis stop is of higher amplitude and lenis stops also show a smaller difference (Δ_{amp}) when compared with the overall amplitude of the following vowel. This is shown in Figure 6.21. The effects of voicing at the burst have not been controlled however and the lenis stops are far more likely to have glottal activity at the moment of the burst (see § 6.5). There is very little difference between the burst amplitude of lenis stops and that of the following vowel. This may be because there is full voicing throughout the entire closure in the lenis stops. The fortis bursts are comparatively weak and consequently may not provide adequate cues to place

of articulation.

6.7.2 A spectral analysis of the burst

In general, the spectral peaks are intrinsic to the place of articulation and consequently they are in the same place for stops at the same place of articulation. They are however affected by the following vowel quality in terms of closeness and backness.

Figure 6.22 shows the average spectral moments at three places at the interface of a bilabial consonant and both front vowels and back vowels for a single male speaker of Biniñ Gun-wok. The first measurement point is at the burst, the second at the maximum RMS amplitude peak within the burst and finally 10 ms into the following vowel. The curves plotted are Linear Prediction Smoothed spectra (LPS) with the corresponding Discrete Fourier Transform (DFT) co-plotted.

The most striking difference between the lenis and fortis stops is found in the lower frequencies. The spectra at the burst show the lenis bilabial stops with a greater amplitude. When the spectra are measured at maximum RMS amplitude the fortis stops show greater amplitude at frequencies of less than 2 kHz—around 20 dB for back vowels and 10 dB for front vowels. This is explained by the higher proportion of fully voiced lenis stops. The fortis stops seem to have greater energy in the frication portion of the stop release, which could indicate difference in the closure. The spectra of lenis and fortis stops at 10 ms after the onset of the vowel tend to be very similar. In general the amplitude peaks occur at the same frequencies. The lowest two amplitude peaks are apparently conditioned by the following vowel.

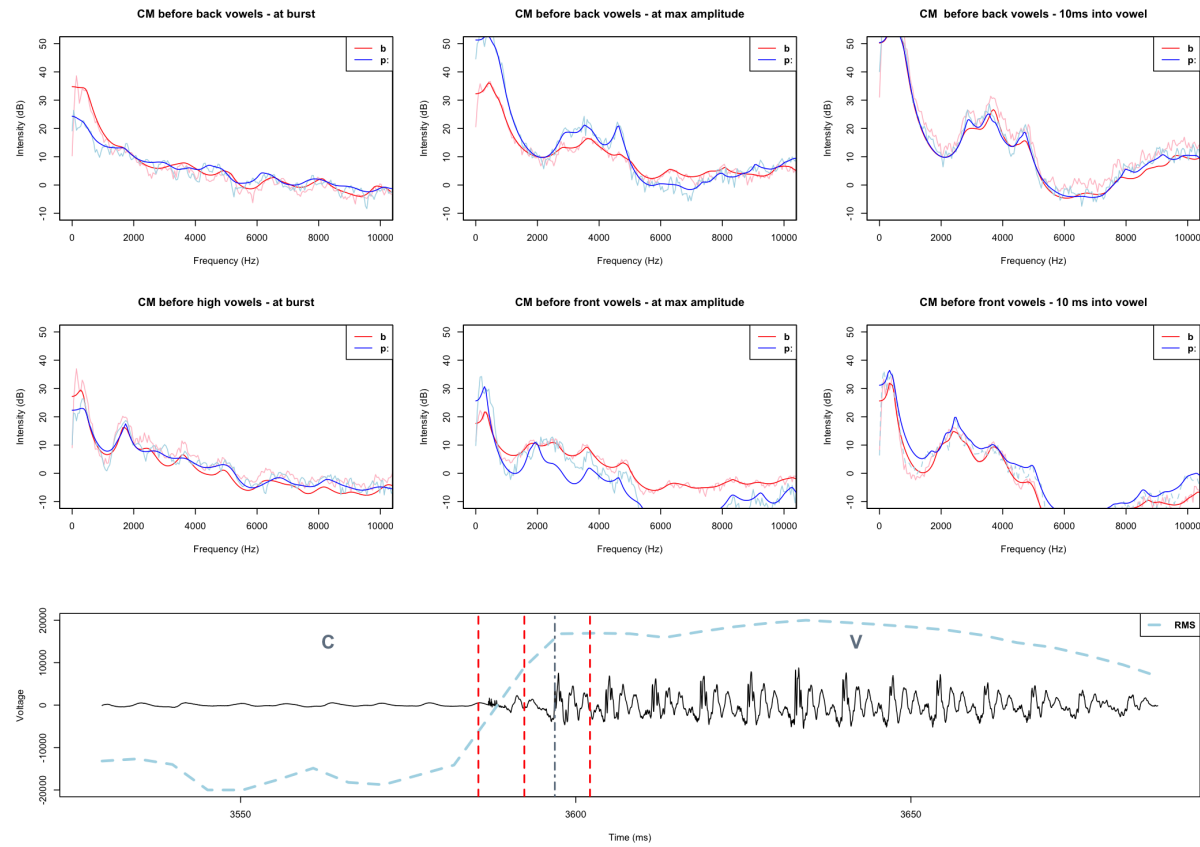


FIGURE 6.22: A spectral slice at three points within a medial bilabial consonant: at the burst, at the maximum RMS amplitude within the VOT and at 10 ms after the onset of the vowel for a male speaker (CM) for back vowels and front vowels.

A similar pattern is shown in Figure 6.23, which plots the spectra for a female speaker at three points during the release phase of the stop. Bilabial lenis stops has higher energy at the lower frequencies when the spectra are measured at the burst with a 7 dB difference in the frequencies under 2 kHz. When the spectra are measured at the maximum RMS amplitude the fortis stops have the higher low frequency energy with a 7 dB difference in the frequencies under 500 Hz. This pattern is not maintained in the spectra of velar stops.

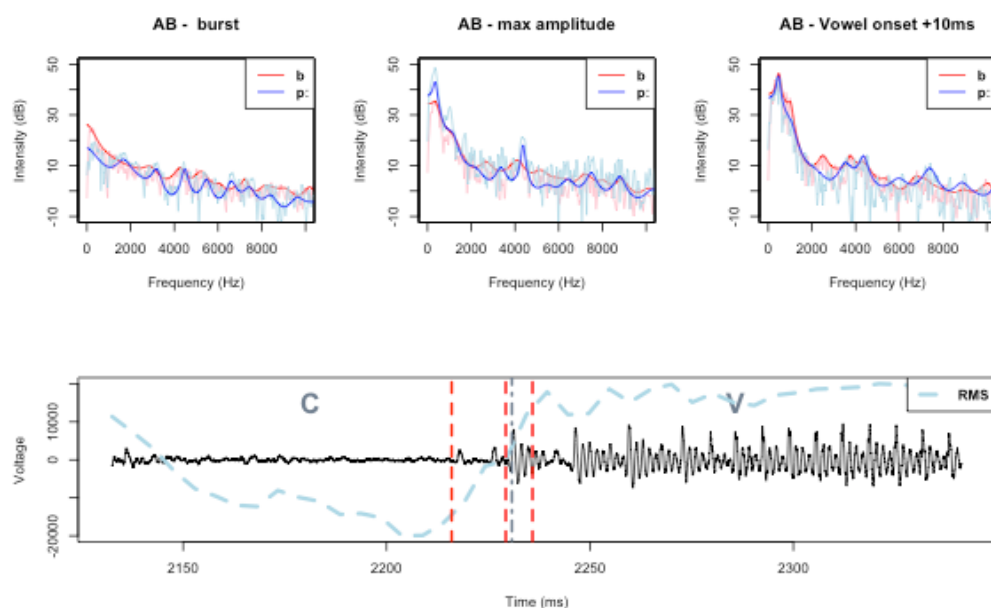


FIGURE 6.23: A spectral slice at three points within a medial bilabial consonant: at the burst, at the maximum RMS amplitude within the VOT and at 10 ms after the onset of the vowel for a female speaker (AB) for back vowels.

Generally the spectral characteristics are very similar for lenis and fortis stops at the same place of articulation as expected given a consistent vowel environment. The differences in the speech spectra are largely dependent on place of articulation rather than differing in relative spectral amplitude based on stop category.

A further spectral analysis at the onset and the offset of the consonant is conducted in Chapter 8). This uses measures of spectral tilt to investigate possible changes in laryngeal tension § 8.6.

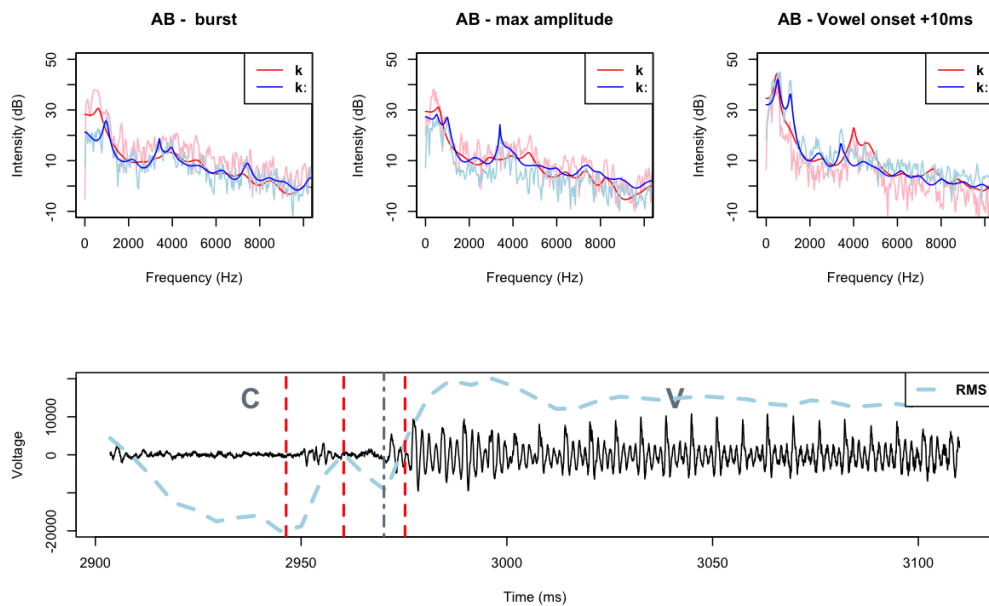


FIGURE 6.24: A Spectral slice at three points within a medial velar consonant: at the burst, at the maximum RMS amplitude within the VOT and at 10 ms after the onset of the vowel for a female speaker (AB) for back vowels.

6.8 Locus equations

As discussed in the method § 5.6.9, locus equations can be useful when investigating both place of articulation and coarticulatory effects between a consonant and the surrounding vowels. The results of locus equations are best represented graphically and the resulting plots summarise a set of regression analyses.

Locus equations have been calculated for each place of articulation and then separated by stop category. Male and females have been measured separately to control for size of vocal tract and the inherent differences in F_2 between sexes. The male speakers are DN, HK and OK and the female speakers MM and JM. A further individual analysis is shown in each of the tables at the end of this section.

The locus equation plots are separated by sex and also by place of articulation. The bilabials are shown in Figures 6.25 (male) and 6.26 (female). The

velars are shown in 6.27 (male) and 6.28 (female). The apicals, shown in 6.29 (male) and 6.30 (female). The palatals are shown in 6.31 (male) and 6.32 (female). Finally, the retroflexes are shown in 6.33 (male) and 6.34. In each of the plots, the regression line is plotted through the points that are labelled by phonetic symbol. Each plot shows the lenis stops in the upper panels with the VC sequence on the left and the CV sequence on the right. The lower panels show the same sequences for fortis stops.

The only place of articulation in which the regression line strongly deviates from a slope of 1 is palatal sequences. This high slope is evident for all speakers (see Figure 6.31 and Figure 6.32).

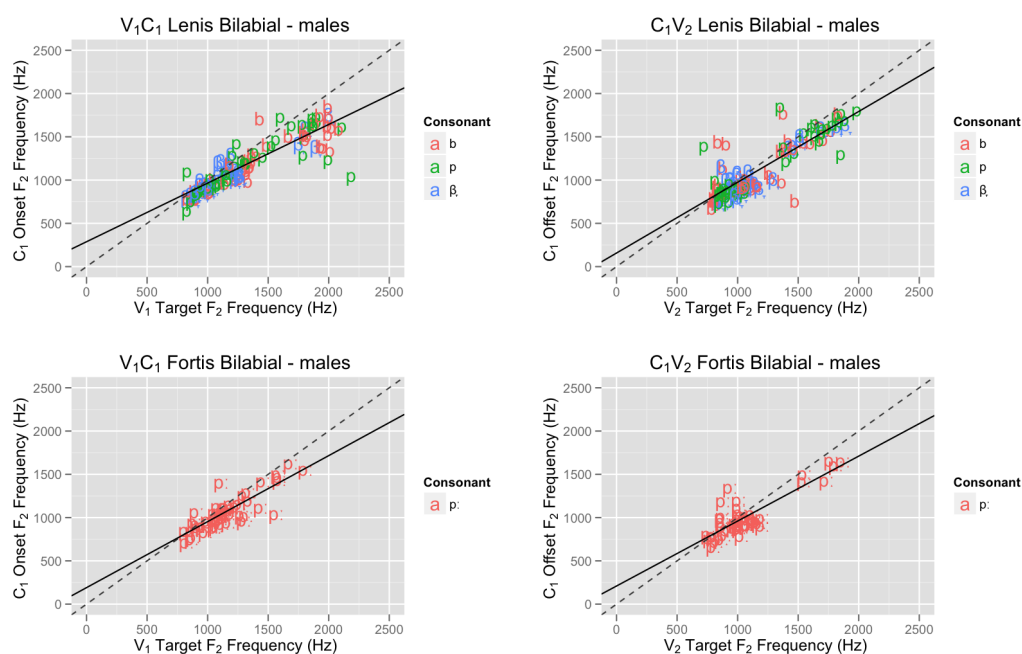


FIGURE 6.25: *Locus equation plot for bilabial stops in VC and CV sequences for male speakers.*

The results of a statistical analysis using the locus equation separated by speaker is summarised in the following tables. The significant p values with an $\alpha < 0.01$ are denoted in bold type. The F statistic values and the adjusted r^2 which shows that the regression line fits more than 85% of the data are also shown in bold. These tables are separated by the sequence type. The fortis and

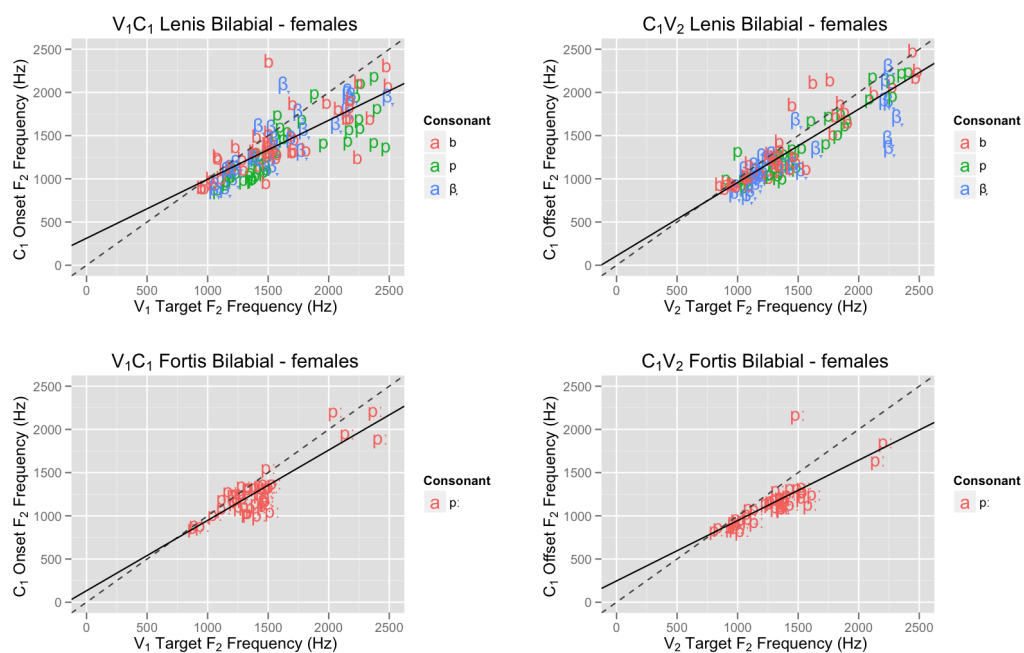


FIGURE 6.26: Locus equation plot for bilabial stops in VC and CV sequences for female speakers.

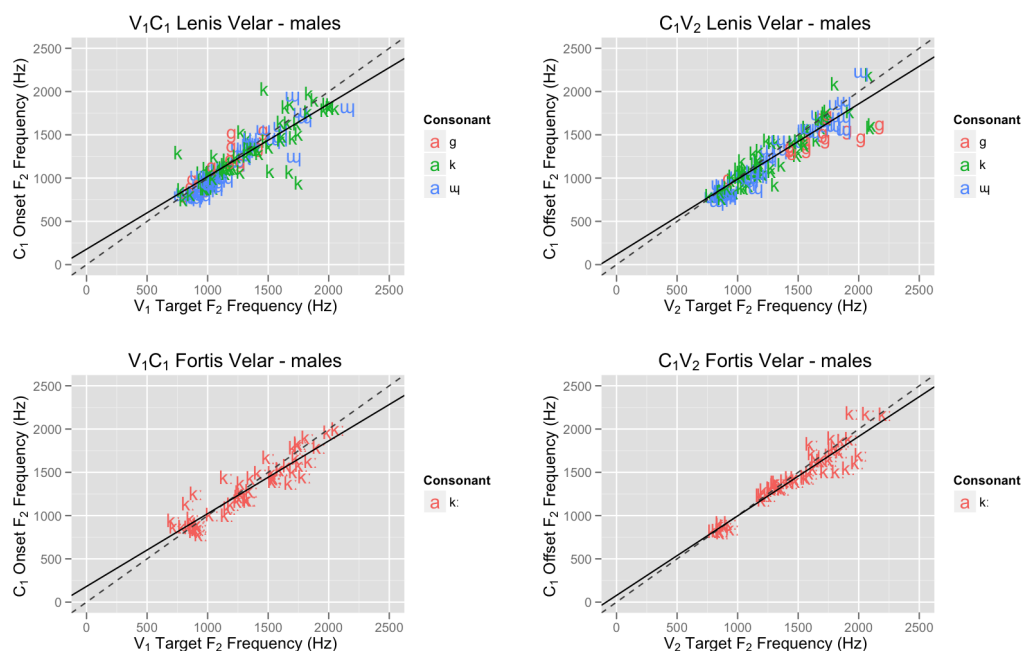


FIGURE 6.27: Locus equation plot for velar stops in VC and CV sequences for male speakers.

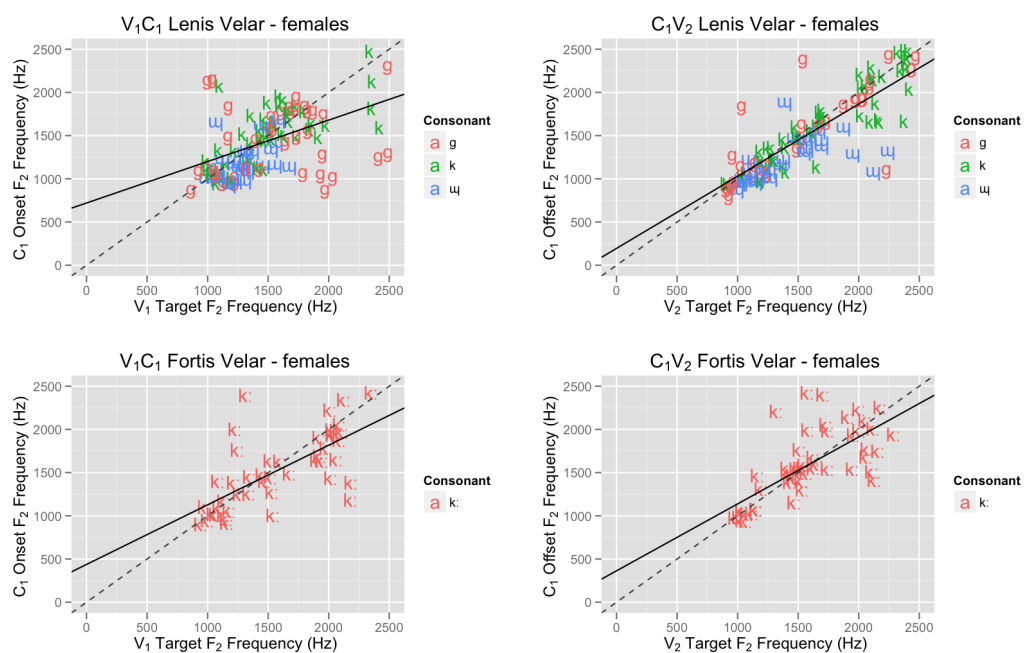


FIGURE 6.28: Locus equation plot for velar stops in VC and CV sequences for female speakers.

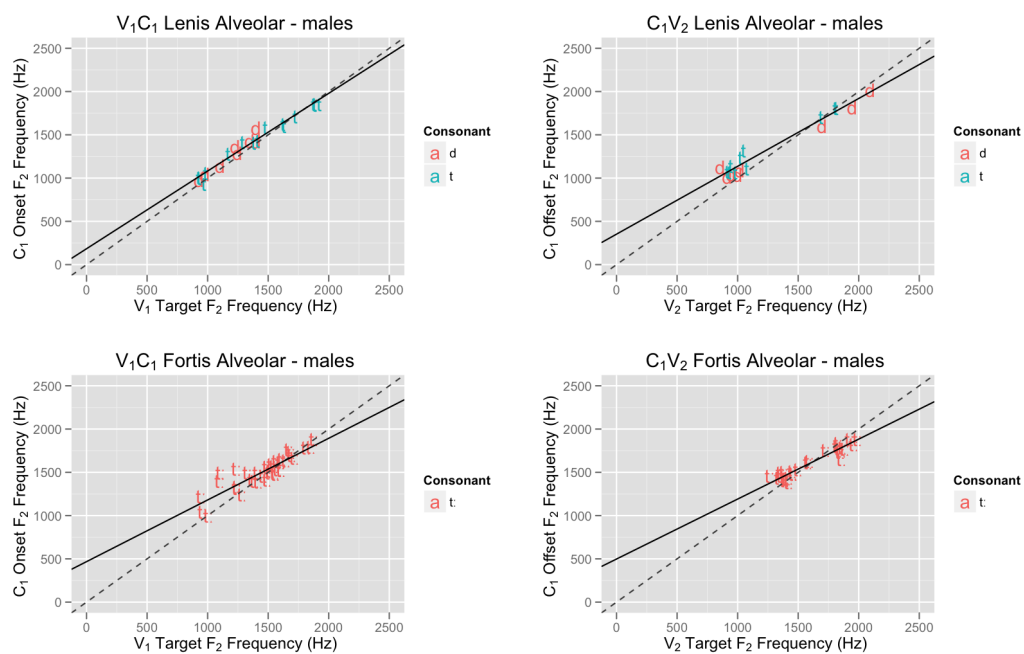


FIGURE 6.29: Locus equation plot for alveolar stops in VC and CV sequences for male speakers.

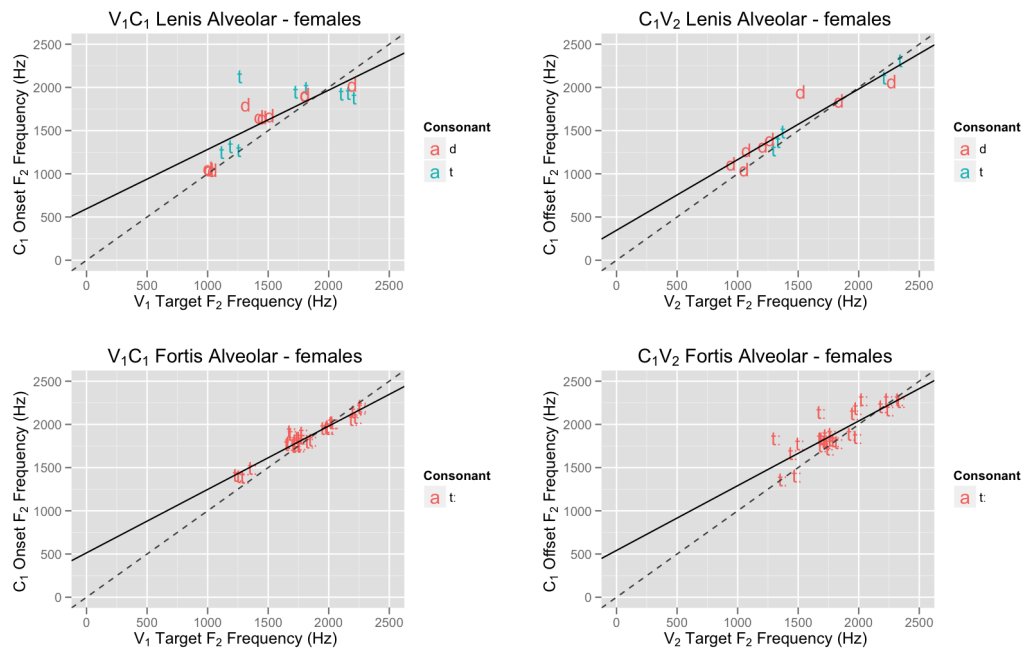


FIGURE 6.30: Locus equation plot for alveolar stops in VC and CV sequences for female speakers.

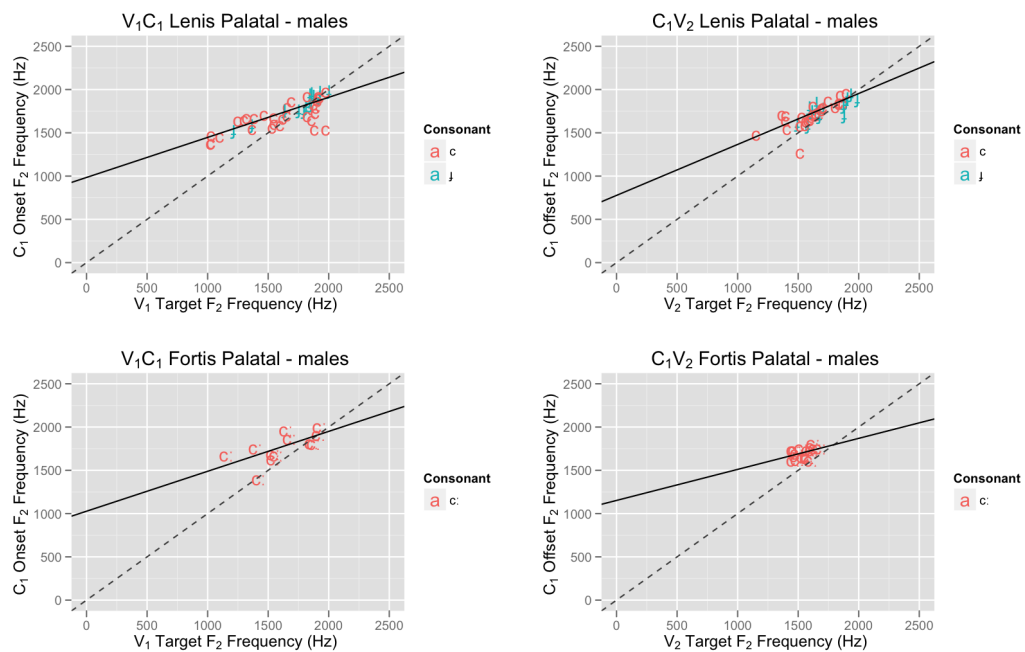


FIGURE 6.31: Locus equation plot for palatal stops in VC and CV sequences for male speakers.

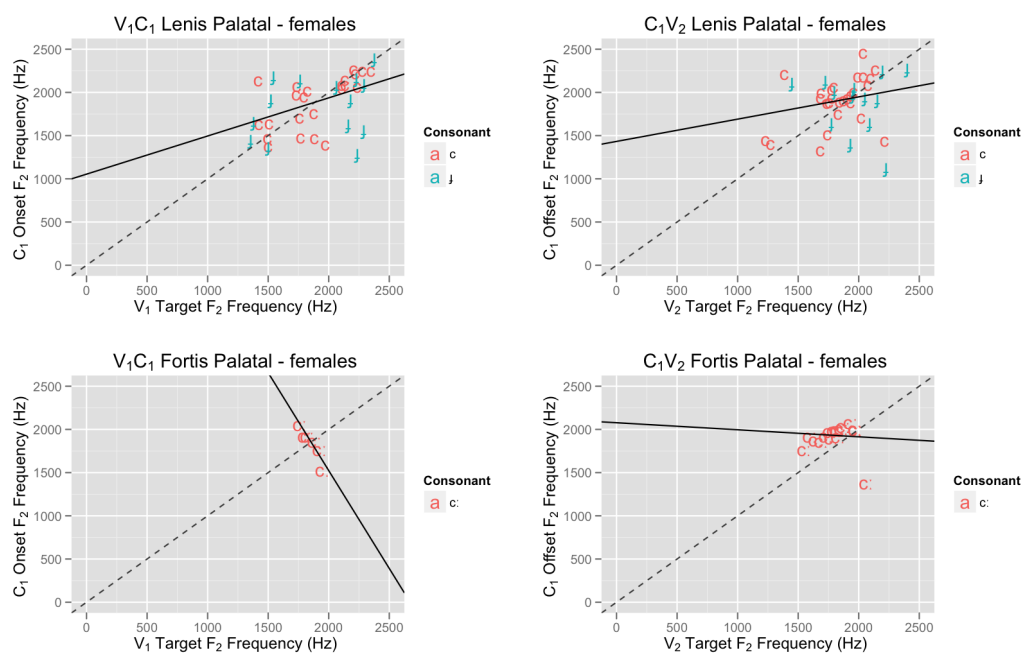


FIGURE 6.32: Locus equation plot for palatal stops in VC and CV sequences for female speakers.

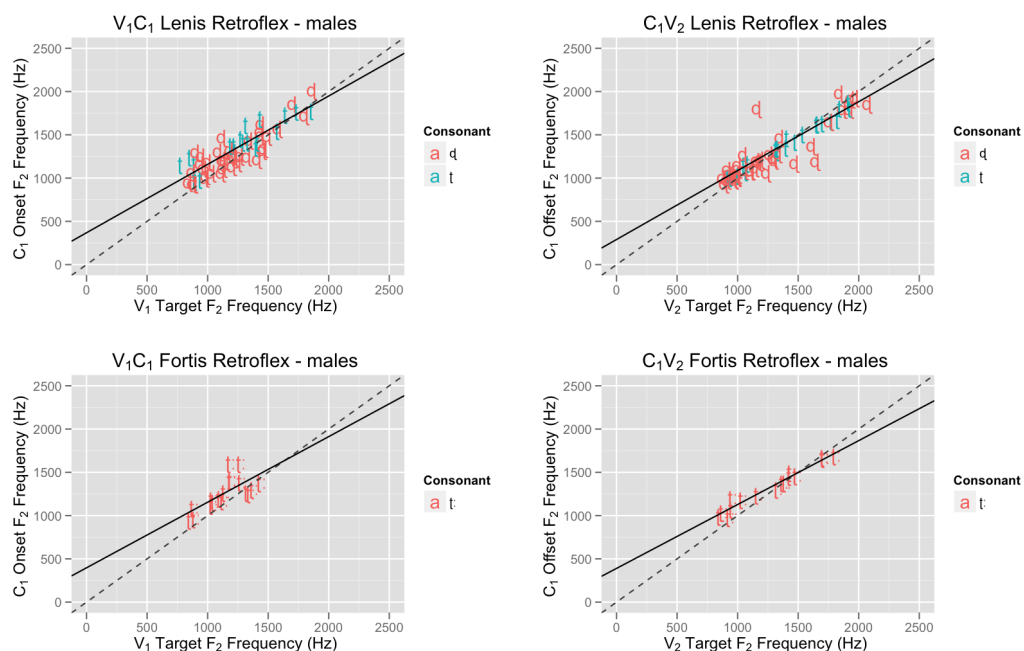


FIGURE 6.33: Locus equation plot for retroflex stops in VC and CV sequences for male speakers.

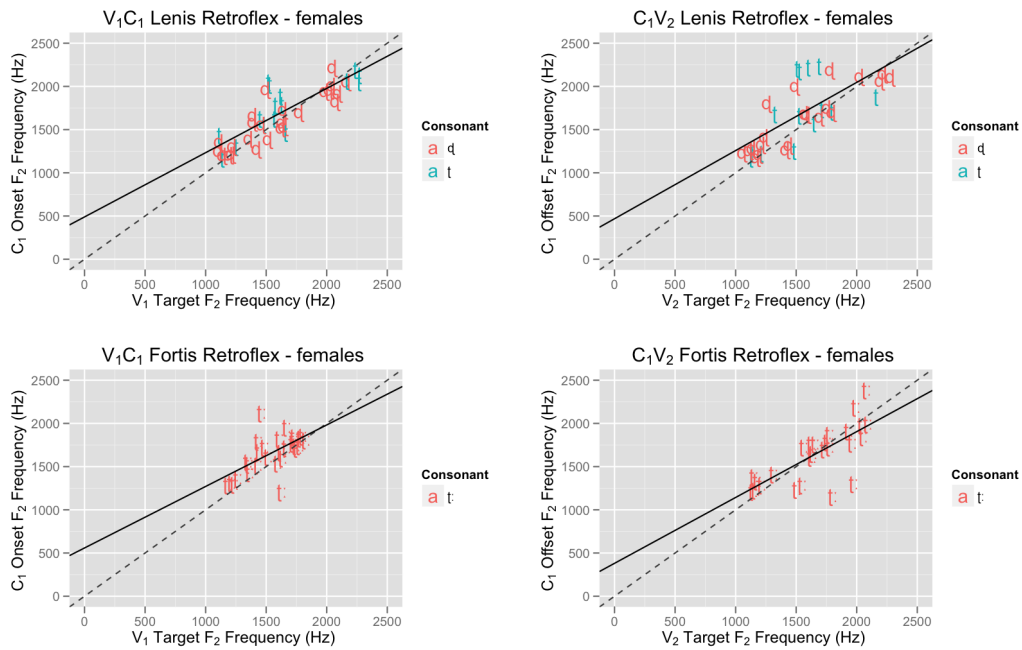


FIGURE 6.34: Locus equation plot for retroflex stops in VC and CV sequences for female speakers.

lenis are shown separately for each table.

The male speakers are shown in Table 6.14, measuring the coarticulation in a vowel (V) followed by consonant (C) sequence (VC). The fortis stops presented first, followed by the lenis stops. The results for male speakers in sequences of a consonant followed by a vowel (CV) are shown in Table 6.15. The results for the female speakers are shown in Tables 6.16 and 6.17.

The statistical results show a high degree of variability. There are no clear differences between the results of locus equations for lenis and fortis stops. Based on these results it is concluded that there are no vowel to consonant coarticulatory effects. The palatal stops are outliers when examining the slope values. Both lenis and the fortis palatal stops exhibit very low slope values. Despite the palatal stops showing very low p values indicating statistical significance. The F statistic is generally low indicating a low probability and the

TABLE 6.14: *Locus Equation Summary for stops (fortis and lenis) in VC sequences, Males.*

speaker	Place	Locus (Hz)	y-int. (Hz)	slope	adj. r^2	F	p
HK	p:	892.9	217.5	0.76	0.65	47.55	p = 0.12
HK	k:	1401	175	0.88	0.88	179.9	p = 0.069
HK	t:	1586	668.2	0.58	0.68	37.08	p < 0.001
HK	c:	1996	547.8	0.73	0.87	35.04	p = 0.061
HK	t̥:	1309	690.3	0.47	0.6	12.8	p = 0.004
OK	p:	750.1	189.5	0.75	0.77	89.93	p = 0.049
OK	k:	985.7	199.7	0.8	0.86	149.5	p = 0.037
OK	t:	1761	317.1	0.82	0.85	95.15	p = 0.019
OK	c:	1908	1150	0.4	0.083	1.455	p = 0.087
OK	t̥:	652.2	-289.1	1.4	0.79	31.54	p = 0.34
HK	b	805.8	217.9	0.73	0.87	430.8	p < 0.001
HK	g	1098	146.3	0.87	0.89	486.9	p = 0.0063
HK	d	1810	200.4	0.89	0.97	364.9	p = 0.012
HK	j	1860	793.5	0.57	0.7	50.81	p < 0.001
HK	ɟ	1637	431	0.74	0.7	61.57	p = 0.0014
OK	b	954.6	359.7	0.62	0.69	140.2	p < 0.001
OK	g	1120	217.6	0.81	0.62	104	p = 0.035
OK	d	1802	161.4	0.91	0.96	284.7	p = 0.059
OK	j	1807	1171	0.35	0.48	20.38	p < 0.001
OK	ɟ	1980	306.6	0.85	0.82	135.3	p = 0.0018

TABLE 6.15: *Locus Equation Summary for stops (fortis and lenis) in CV sequences, Males.*

speaker	Place	Locus (Hz)	y-int. (Hz)	slope	adj. r^2	F	p
HK	p:	806.5	211.9	0.74	0.63	41.76	p = 0.1
HK	k:	1026	140.1	0.86	0.91	259.8	p = 0.1
HK	t:	1533	494.6	0.68	0.92	159.7	p < 0.001
HK	c:	727	-100.8	1.1	0.35	5.266	p = 0.9
HK	t̥:	1455	467.6	0.68	0.88	51.86	p = 0.01
OK	p:	880.2	215.4	0.76	0.78	88.09	p = 0.027
OK	k:	-1668	-10.73	0.99	0.91	258.9	p = 0.91
OK	t:	1723	510.5	0.7	0.96	286.1	p < 0.001
OK	c:	1828	1198	0.34	0.26	3.741	p = 0.0033
OK	t̥:	1509	380.9	0.75	0.96	179.3	p = 0.0019
HK	b	656.1	104.3	0.84	0.82	281.3	p = 0.1
HK	g	984.4	114.8	0.88	0.88	469.2	p = 0.043
HK	d	1538	371.8	0.76	0.94	135.9	p = 0.004
HK	j	1873	857.2	0.54	0.7	48.3	p < 0.001
HK	ɟ	1488	192.5	0.87	0.94	431.1	p = 0.0033
OK	b	1018	208.7	0.8	0.63	105	p = 0.027
OK	g	847.2	122.1	0.86	0.83	316.7	p = 0.064
OK	d	1804	313.3	0.83	0.97	303.5	p = 0.0014
OK	j	1923	690.6	0.64	0.48	19.22	p = 0.0095
OK	ɟ	1380	387.2	0.72	0.73	82.96	p < 0.001

TABLE 6.16: *Locus Equation Summary for stops (fortis and lenis) in VC sequences, Females.*

speaker	Place	Locus (Hz)	y-int. (Hz)	slope	adj. r^2	F	p
JM	p:	1020	273	0.73	0.81	96.89	p = 0.02
JM	k:	1400	418.8	0.7	0.48	23.06	p = 0.077
JM	t:	1862	494.9	0.73	0.93	212.6	p < 0.001
JM	c:	1884	10730	-4.7	0.72	6.198	p = 0.21
JM	t̥:	1789	334.6	0.81	0.63	26.61	p = 0.21
MM	p:	-2044	-93.72	0.95	0.73	49.02	p = 0.64
MM	k:	1431	460	0.68	0.4	14.3	p = 0.16
MM	t:	2013	559.1	0.72	0.95	222.5	p < 0.001
MM	c:	1850	5968	-2.2	0.74	6.614	p = 0.16
MM	t̥:	2952	413.1	0.86	0.25	4.993	p = 0.49
JM	b	1020	228.4	0.78	0.7	129.4	p = 0.049
JM	g	1394	914.2	0.34	0.11	7.939	p < 0.001
JM	d	2074	584.1	0.72	0.52	12.87	p = 0.088
JM	j	1758	1238	0.3	0.032	1.598	p = 0.013
JM	ɗ	1822	395.5	0.78	0.76	70.06	p = 0.015
MM	b	955.5	382.9	0.6	0.6	91.33	p < 0.001
MM	g	1335	493.5	0.63	0.46	50.56	p < 0.001
MM	d	1703	526.9	0.69	0.76	19.81	p = 0.1
MM	j	2112	857.7	0.59	0.51	18.85	p = 0.0052
MM	ɗ	1982	666.1	0.66	0.64	30.78	p = 0.0052

TABLE 6.17: *Locus Equation Summary for stops in CV sequences, female speakers.*

speaker	Place	Locus (Hz)	y-int. (Hz)	slope	adj. r^2	F	p
JM	p:	703.3	132.3	0.81	0.44	19.4	p = 0.58
JM	k:	1863	236.9	0.87	0.58	36.12	p = 0.31
JM	t:	2156	637.1	0.7	0.48	15.04	p = 0.075
JM	c:	2262	893.2	0.61	0.71	20.84	p = 0.0061
JM	t̥:	1545	544.3	0.65	0.4	9.07	p = 0.16
MM	p:	753.4	242.8	0.68	0.89	157.3	p = 0.005
MM	k:	1538	447.1	0.71	0.39	16.18	p = 0.15
MM	t:	2128	435.9	0.8	0.87	77.21	p = 0.029
MM	c:	1897	3410	-0.8	0.074	1.641	p = 0.022
MM	t̥:	1703	303.6	0.82	0.54	15.09	p = 0.43
JM	b	915.4	104.8	0.89	0.78	199.5	p = 0.26
JM	g	1181	413.9	0.65	0.51	54.07	p = 0.0038
JM	d	1923	399.7	0.79	0.82	32.26	p = 0.097
JM	j	1899	1827	0.038	-0.055	0.01301	p = 0.012
JM	ɗ	2185	384.7	0.82	0.69	41.75	p = 0.068
MM	b	443.9	70.01	0.84	0.86	347.4	p = 0.33
MM	g	1237	99.53	0.92	0.8	250.5	p = 0.33
MM	d	1773	189.6	0.89	0.98	187.1	p = 0.2
MM	j	2026	1112	0.45	0.14	4.13	p = 0.014
MM	ɗ	2161	642.1	0.7	0.3	7.414	p = 0.15

adjusted r^2 is also low, indicating that the regression line does not accurately reflect the majority of the data points.

When considering each place of articulation, the alveolars have the most consistent loci at around 1800 Hz for lenis stops of male speakers. These are consistently statistically significant. The bilabials generally have a lower locus, below 1000 Hz. The velars have highly inconsistent values in their loci which could be a function of their very high slopes. This inconsistent result also describes the patterning found in the apico-postalveolar stops (labelled retroflex here). In terms of the loci, the results for palatals, alveolars and bilabials are consistent with previous studies of Australian languages and of stops in other languages (Graetzer, 2012; Tabain & Butcher, 1999b).

In conclusion, at each place of articulation there is very little difference between lenis and fortis stops. Interestingly however there also is no obvious difference between VC and CV sequences unlike results for other languages. Generally these data show that there is very little effect of the consonant on the preceding vowel in bilabials which as the tongue is not active in their articulation. The coronals had more effect on preceding vowels with the palatals [c: c j] exerting the most obvious effect on the preceding vowel at C₁ onset and the following vowel at C₁ offset (Figures 6.31 and Figures 6.32). These place of articulation patterns showed to be very similar for all speakers but they were not strong enough to draw further conclusions regarding coarticulatory effects.

This section of the experiment was designed to test whether the stops patterned differently at the onset or the offset of the consonant indicating greater articulatory strength in either direction. This was not confirmed, however. It should be noted that similar locus equations were calculated for nasals with similarly inconclusive results but these results are not presented here.

6.9 Discussion

6.9.1 Duration

The results show that positing a phonetic basis for the phonologically contrasting stops in Bininj Gun-wok is justified. This is a difference that is primarily based on total consonant duration, similar to that found in many other of the world's languages. When each speaker is analysed separately there is clear separation between the two stop categories based on duration. Place of articulation does not contribute to the difference, however, particularly when looking within the fortis category. The lenis stops on the other hand, show considerable variation within the category in terms of both duration and levels of voicing.

The ratio of lenis to fortis durations are consistently in the order of 1:2 and sometimes higher for some speakers (see Table 6.4 and Figure 6.4). Modarresi (2002, p. 56) found that in Persian there were closure duration ratios of between 2.20 (velars) and 3.46 (bilabials) when comparing geminates and singletons. The velars did not exhibit consistently higher ratios than bilabials or any of the other places of articulation in Bininj Gun-wok.

The alveolars had a consistently high set of ratios for the three speakers in which the ratio is reported. For DN and JM the ratios are over 1:4 and 1:3 respectively. This indicates that the lenis alveolars have a relatively short duration, at 33 ms and 48 ms respectively for DN and JM. Speaker HK had a longer average duration for lenis alveolars compared with the other speakers at 77 ms compared with 120 ms for fortis alveolars. In general HK showed less difference between lenis and fortis durations although all of the ratios were above 1:1.5 when place of articulation was taken into account.

Within Corpus II, which looked at the bilabial and velar places of articulation, there is a similar separation based on duration when each speaker is considered separately (see Figure 6.5). Statistical analysis showed that when speaker and token identity was taken into account a main effect of stop category

on stop duration is significant.

Generally there is a high degree of variation within the lenis stop category that was not found within the fortis stops category. There was a high incidence of approximation of lenis stops intervocalically and these approximants generally had shorter durations than stops that achieve full closure.

6.9.2 Voice onset time

Positive VOT values are consistently very short and mostly any difference between them can be explained with reference to physiological factors such as cavity size. As found by Fischer-Jørgensen (1954) and Peterson and Lehiste (1960), the further back in the vocal tract the closure is the longer the VOT. Results show that velars have relatively high values for VOT but values far shorter than usual cross-linguistically. Stevens et al. (1986) found that articulations with a more extended contact area, such as lamino-palatals in Biniŋ Gun-wok (labelled [c,c:] and [ɟ]), have a longer VOT which is common for this class of consonant amongst Australian languages. In Biniŋ Gun-wok, the fortis palatals have the highest mean VOT. The apicals show the shortest positive VOT, with apico-alveolars showing a mean VOT of 15 ms and apico-postalveolars (retroflexes) showing a mean VOT of 17 ms. These values are in line with cross-linguistic results found by Cho and Ladefoged (1999, p. 208) for apicals. In summary, the average VOT values are very short, putting them in the short-lag category proposed by Lisker and Abramson (1964). Cross-linguistically they pattern more closely with coincident VOT values such as those found in French (Cho & Ladefoged, 1999).

When comparing lenis and fortis, the VOT for lenis stops—with a positive VOT and a clear burst—was not significantly different to the VOT of fortis stops when the interaction between speaker and place of articulation was examined. The negative VOT values are associated exclusively with the lenis stops. This shows that negative VOT does not consistently differentiate lenis stops from

fortis stops but they do vary consistently with place of articulation in line with results from other languages. Whether this is sufficient as a perceptual cue to place of articulation is debatable however, as the values are almost co-incident with the onset of voicing.

6.9.3 Voice termination time

Voicing can extend into the closure in both lenis and fortis medial stops. The amount of voicing changes for each speaker are dependent on place of articulation. In general, the VTT for the lenis stops is much longer than that of the fortis stops for all places of articulation. The VTT can extend the entire duration of the stops although these tokens are not included in this analysis. The regular laryngeal activity extending after the stop closure is a prolongation of voicing rather than voicing associated with a negative VOT. These have been separated as shown in Figure 6.6 in § 6.5.

The VTT is appreciably longer for lenis stops due to evidence of active prolongation of voicing or possibly passive devoicing in some instances. The fortis stops seem to be actively devoiced however, as the VTT is generally shorter. There is a high degree of variability between speakers but in general the bilabials have longer VTT in both lenis and fortis stops due to the greater cavity volume behind the closure and greater surface area of flexible tissue in the cheeks that can expand when the intra-oral pressure rises.

Similar findings have been reported by Lo (2010) in the languages Bardi, Kayardild, Warlpiri, and the Yolngu Matha dialect Yan-Nhangu. Lo argues that the Anderson and Maddieson (1994) hypothesis, which describes Tiwi stops as passively devoiced, is the most compelling. This conclusion will be discussed further in the following chapter.

6.9.4 Vowel to consonant ratios

In general, the vowels that precede fortis stops are marginally shorter than vowels that precede lenis stops but they only differ by about 12 ms. As shown in Figure 6.17, for the speakers in Corpus I, when comparing the duration of lenis stops with that of the preceding vowel, as the stop duration increases the vowel duration decreases. This effect is not as strong when comparing the durations fortis stops with that of the preceding vowel. As the fortis stop increases in duration the vowel does not increase in duration. This effect is not consistent in Corpus II however. A consistent vowel to consonant ratio in preceding vowels is not observed within this sample. The observation in other languages that there are shorter vowels before voiceless segments is not observed here.

A similarly non-significant result is found in vowels following lenis and fortis stops (V_2) and there is even greater variability here as there is probably influence of the following consonant, the identity of which has not been controlled.

6.9.5 Non-durational measurements

The non-durational acoustic measurements were less successful than duration measurements at signalling a difference between the stop categories. Burst amplitude does prove to be a significant factor between the stop categories. The lenis category shows a higher mean burst amplitude than the mean amplitude in the fortis bursts. This may indicate that although there is a clear release burst within many stops in the lenis category, voicing remains. These clear release bursts may show that the lips are not as tightly closed during the closure period of these stops. This possibility will be discussed further in the conclusion of the next chapter.

The burst may provide spectral information that is a cue to place of articulation. Spectral analysis of the burst shows that the major focus of energy in

the stop types is in the lower frequencies, associated with voicing; although the bursts in lenis stops tend to have a slightly higher amplitude overall. The analysis of burst spectra in Bininj Gun-wok is not exhaustive for each place of articulation and future work could examine some of the spectral differences suggested here. The results show that lenis and fortis stops at the same place of articulation have very similar burst spectra when the vowel environment is kept constant. As mentioned above, the lower frequencies are the primary difference between them and this may account for the differences in burst amplitude. In Figure 6.24 which shows the velar place of articulation for the female speaker AB, there are sharper spectral peaks when compared with the bilabial place of articulation for the same speaker. After the onset of voicing in the following vowel the spectra are very similar, comparing lenis and fortis stops at the same place of articulation and in the same vowel environment. These spectra have not been compared statistically however, but the results suggest that burst amplitude alone is not a sufficient parameter for signalling a difference between lenis and fortis stops.

6.9.6 Coarticulatory effects

Although the coarticulatory effects of a medial consonant's effect on the vowel was extensively examined there is no evident difference in either the locus values or the slope values of the locus regression. The results clearly show that coarticulatory effects do not differ based on stop category. The predicted sharper cues to place of articulation that would be expected for fortis stops if there is in fact a greater articulatory movement when compared with lenis stops are not clearly observed.

These results, particularly with regard to palatals, are remarkably similar to results reported by Graetzer (2012) for Arrernte, Warlpiri, Gupupuyngu and Burarra. For both males and females the slope values are low and the y-intercept high. This effect may be due to the larger relative mass of the tongue dor-

sum, which is more constrained in terms of articulation than both of the apical places of articulation that use the tongue tip. Palatals are found to be highly coarticulation resistant as they are in other languages (see § 3.2.2).

The locus values generally are very consistent at each place of articulation across the speakers, regardless of the stop category. Despite this, the statistical analysis did not meet the critical alpha level set for significance ($p > .001$) in most cases and could not be relied upon to prove a difference between the groups measured. The locus equations did not sufficiently describe the majority of data. This suggests that there is no difference in the influence of intervocalic lenis and fortis stops on the preceding and following vowel. This symmetrical aspect of the coarticulation patterns is in contrast to languages such as English, as shown by Tabain et al. (2004) using a similar locus metric.

6.9.7 Concluding remarks

This chapter has detailed some of the acoustic results and has shown that length or phonetic duration to be the most consistently significant factor in cueing the contrast. When attempting to describe and quantify the articulation of stop consonants the acoustics are only partially able to delineate the phonetic differences between the stop categories. The stop categories differ in terms of *length* but do they differ in terms of *strength*?

The following chapter re-examines differences between lenis and fortis stops with the inclusion of aerodynamic and articulatory data into the analysis. Phonetic differences in terms of strength or force of articulation are explored and in addition the patterning of voicing found at medial stop closure is described. The addition of articulatory data enable the internal composition of clusters in Bininj Gun-Wok to be carefully described and the durational similarities between fortis stops and cluster to be examined in greater detail.

Chapter 7

An aerodynamic analysis of stops

This chapter details a physiological description of medial stops in Biniŋ Gun-wok. The investigation looks at differences in articulatory strength between the two previously defined phonological stop categories. The preceding chapter proposes that duration is the most consistent phonetic difference between the categories. This chapter is a systematic reanalysis of lenis and fortis stops that looks beyond these durational results in order to see if there is a difference in strength between the stop classes. The results for this experiment are divided into two sections. The first in this chapter, reports the results of an aerodynamic analysis and follows on closely from the findings reported in the previous chapter. The second, detailed in the following chapter (Chapter 8), concentrates on duration differences and voicing contrasts between the categories. Possible articulatory explanations are posited based on the observed articulatory patterns. The central question is what are the phonological consequences of changes in speech aerodynamics in Biniŋ Gun-wok?

7.1 Aims

This experiment is divided into two chapters and the general aims of the experiment are set out above in § 4.5. The three main aims are:

- i. To investigate differences between lenis and fortis stops in Biniŋ Gun-wok that go beyond duration using aerodynamic data.
- ii. To look beyond length toward strength or measures of articulatory effort.

The first aim is central to the study and relates directly to the acoustic analysis of the previous chapter (Chapter 6). This is examined in this chapter (below).

In the following chapters the aerodynamic differences between lenis and fortis stops in Biniŋ Gun-wok are investigated and in addition, three further questions are posed:

- a) Is there evidence of a difference in tension in the larynx preceding or following lenis and fortis medial stops?
- b) Is there any evidence for an active glottal abduction gesture in either lenis or fortis stops?
- c) Is there any difference between the lenis and fortis stops dependent on place of articulation and are there any differences between the coarticulatory patterns of lenis and fortis stops and the surrounding segments?

The inclusion of aerodynamic data are essential for inferring glottal setting in stop transitions as well as providing information on the levels of both respiratory and muscular effort. These aerodynamic data also quantify the variability in articulation observed by a number of researchers in Biniŋ Gun-wok and related languages. In addition the combination of electroglottographic and derived acoustic measures enables detailed investigation of the patterns of voicing in lenis and fortis stops (see § 8.6).

7.2 Methods and materials: aerodynamic analysis

The methodology for the aerodynamic experiments is detailed in § 5.7 and the methodology used for the voice analysis can be found in § 5.8.1. Below is a brief summary of the speakers, stimuli and the word lists unique to this experiment.

7.2.1 Speakers

A total of 12 speakers were recorded with multi-channelled aerodynamic recordings. Of these 12 speakers, a subset of six speakers—three males and three females—are used in this analysis. This subset is because they have the most complete set of data. These data are all drawn from Corpus II.

7.2.2 Stimuli

As in the acoustic experiment detailed in Chapter 5, the stimuli were embedded in the same carrier phrase used for the acoustic experiment in Chapter 6. The stimuli presented all contain medial bilabial stops in either initial, medial or final position. Other places of articulation were recorded for airflow and Laryngographic records. There were also some clusters involving bilabial stops and stops at another place of articulation that are used in subsequent sections of the experiment.

In this experiment the word list was reduced significantly to a list of eight words shown in Table 7.1. This uses words that are attested as homo-morphemic lenis and fortis stops. The geminates that are analysed in the following chapter (Chapter 8) which add a further six words. This brings the total words in the analysis up to 14 words (see Table 8.1).

TABLE 7.1: Word list - Aerodynamic.

CAT.	ID	WORD	STRUC.	PHONETIC	GLOSS
FORTIS					
	A01	kabbal	VC:V	['kɛp:ɐl]	<i>flood plain</i>
	A02	ngabbard	VC:V	['ŋɛp:ɐd] [ɛp:ɐt]	<i>kinship term (F)</i>
	A03	kubbunj	VC:V	['kʊp:ʊŋ]	<i>canoe</i>
	B22	djobbo	VC:V	['cɔp:ɔ]	<i>butcher bird (Dalabon)</i>
LENIS					
	B00	aba	VCV	['ɛbɐ]	<i>interjection</i>
	B05	kabo	VCV	['kɛbɔ], ['gɛbɔ]	<i>green ant</i>
	B06	bobo	VCV	['pɔbɔ], ['bɔbɔ], ['bɔpɔ]	<i>goodbye</i>
	B08	bibom	VCV	['bɪbɔm], ['bɪpɔm]	<i>hit</i>

7.2.3 Distribution

Due to the tokens selected for analysis, all speakers have twice the number of fortis stops than lenis stops. Figure 7.1 shows the distribution of lenis and fortis stops in the aerodynamic corpus. This imbalance in the sample requires the use of robust statistical methods that manage the impact of missing values. As in the other experimental chapters, linear mixed effects models are used to test for significance between groups, the sample consists of three males (CM, TD and DM) and three female speakers (BN,DJ,RN) all recording of which belong to Corpus II (§ 5.2).¹

¹Note: the speaker DM is labelled as DN in some figures. In this chapter DM and DN refer to the same speaker from Corpus II who is distinct from the speaker DN included in Corpus I.

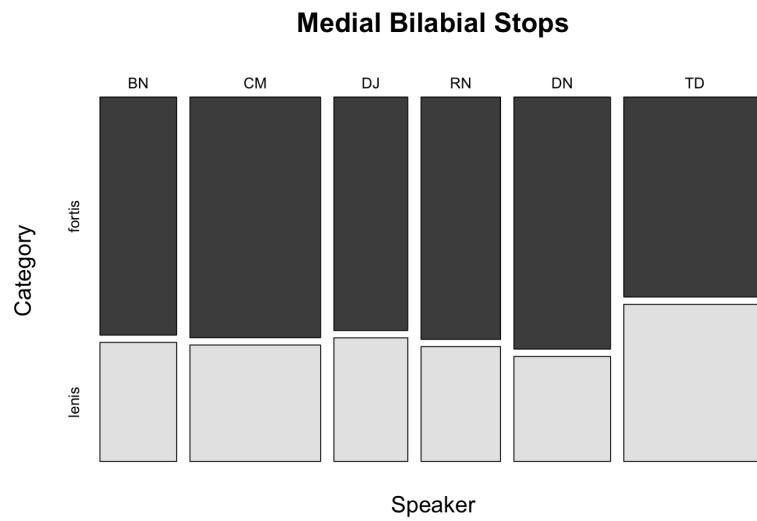


FIGURE 7.1: *Distribution of lenis and fortis in aerodynamic corpus stops by speaker.*

Table 7.2 shows the distribution of the words included in the preliminary analysis separated by speaker. This preliminary analysis restricts the included words to those containing attested intra-morphemic lenis and fortis medial stops. Every effort has been made to exclude words containing inter-morphemic geminates and these will be discussed in the following chapter (Chapter 8).

TABLE 7.2: *Distribution of words by speaker within in the corpus.*

	BN	CM	DJ	RN	DN	TD
aba	1	2	0	0	0	0
bibom	2	1	3	3	0	0
bobo	4	5	3	3	4	10
djobbo	5	4	6	4	0	0
kabbal	5	11	6	5	14	12
kabo	2	8	3	3	4	12
kubbunj	3	6	2	5	2	6
ngabbard	5	9	3	5	10	10

7.3 Results

The results for this experiment are presented in the following sections and summarise the aerodynamic analyses.

The results of peak oral flow (U_o) and peak intra-oral pressure (P_o) measured at the burst are reported. This is followed by an investigation of the interaction between these categories. This explores interaction between pressure and flow and then looks at any correlation between aerodynamics and burst amplitude. The voicing analysis is discussed further in the following chapter § 8.6.

TABLE 7.3: Number (n), mean maximum oral flow rate ($\bar{U}_o$) measured in cubic centimetres per second ($\text{cm}^3 \text{s}^{-1}$), mean maximum oral pressure ($\bar{P}_o$) measured in Pascals (Pa) for bilabial fortis and lenis stops separated by speaker.

Speaker	FORTIS		LENIS	
	$\bar{U}_o$ ($\text{cm}^3 \text{s}^{-1}$)	$\bar{P}_o$ (Pa)	$\bar{U}_o$ ($\text{cm}^3 \text{s}^{-1}$)	$\bar{P}_o$ (Pa)
CM	459	429	357	245
DN	358	323	296	129
TD	464	574	264	123
BN	179	460	123	222
DJ	148	316	206	169
RN	181	484	115	206

The mean values for peak pressure and peak flow are shown in Table 7.3. All of these values represent the maximum levels of flow and pressure measured closest to the stop release. The oral airflow measurements (U_o) at the stop release can be in a variety of positions with respect to stop voicing such as just prior to the onset of voicing in the following vowel, coincident with the voicing, or slightly after voicing has commenced. There are a number of distinct patterns found when the peak intra-oral pressure is measured. For fortis stops the pressure rises quickly and remains steady for most of the closure period. In lenis stops the rise is more gradual and there is not the associated steady state in the peak pressure. Mean intra-oral pressure is greater for fortis stops when compared to lenis stops for all speakers whereas there was variability across

speakers when comparing the lenis and fortis stops.

When comparing peak U_o (U_o^{MAX}) A LMEM (including stop category as a fixed factor, speaker and token as random factors) shows no significant difference between the stop categories as the result of the likelihood test do not allow the rejection of the null hypothesis ($\chi^2(8, N=211) = 1.29, p = .26$). There is a strong difference between lenis and fortis in terms of peak intra-oral pressure (P_o^{MAX}) ($\chi^2(8, N=211) = 23.4, p < .001$) (same factors included).

7.3.1 Peak pressure vs. peak air-flow in oral Stops

To investigate any interaction between pressure and flow at the stop release, these are plotted and Figure 7.2 shows the results of peak flow rate (Peak U_o) when compared with peak intra-oral pressure (Peak P_o). These compare a subset of words containing medial lenis and fortis stops shown in Table 7.1.

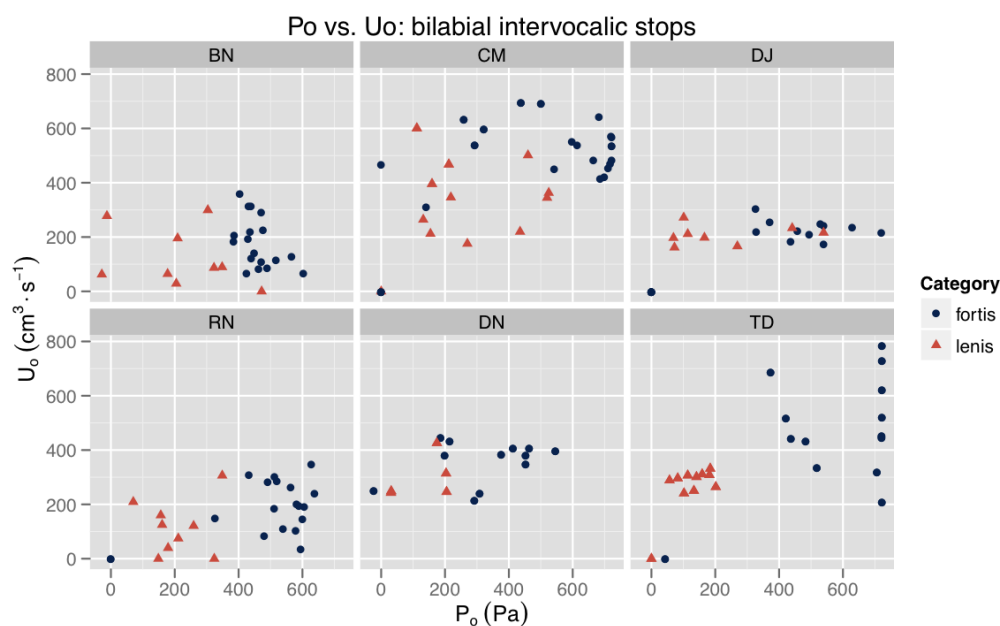


FIGURE 7.2: Intra-oral pressure (P_o shown on the x-axis in Pa) and Oral Flow (U_o shown on the y-axis in ml s^{-1}) for lenis and fortis stops separated by speaker.

The majority of the fortis tokens have both a higher peak oral flow (Peak U_o) and peak oral pressure (Peak P_o) when compared with the lenis tokens

but, as discussed above, the statistical analysis show that only peak pressure is significantly different for the stop categories and this model includes speaker as a random factor.

The stop categories show separation for each speaker. The female speakers (BN, RN and DJ) generally have higher peak intra-oral pressure in fortis tokens but similar levels of oral flow for both lenis and fortis tokens.

It is notable that the male speaker TD has a number of peak pressure values that are very high and very similar (approximately 700 Pa). Speaker CM too has pressure values topping out around the 700 Pa mark. These values may indicate overloading of the pressure transducers.²

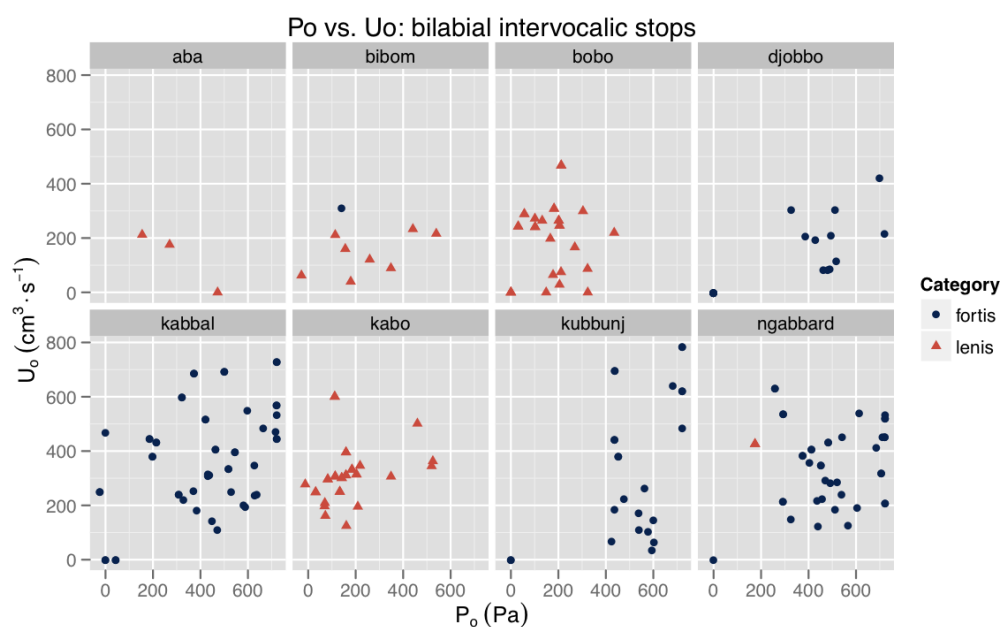


FIGURE 7.3: Intra-oral pressure (P_o in Pa) vs. Oral Flow (U_o in ml s^{-1}) for bilabial lenis and fortis stops separated by word.

In Figure 7.3 the same data as that in the previous figure (7.2) is separated by word and also by speaker (denoted by the shape of the plotting character).

²The gain settings were at the lowest values but the speaker TD consistently produced utterances with a higher amplitude than other speakers, both male and female. This may have been to do with the atmospheric conditions of the field site at that time of year (October, 2007).

Generally, the lenis stops display lower pressure and flow values and also there is less variability within the words. The tokens of the words *bobo* and *kabo* both cluster together. The words containing fortis stops (*kabbal*, *kubbunj* and *ngabbard*) show higher pressure and flow values. There is high within speaker variation as well as between speakers, which is shown in Figure 7.3.

In both of the above figures (7.2 and 7.3), the lenis and fortis stops show some separation. This is mainly evident in the pressure dimension rather than for air flow. For many of the speakers the oral flow values are similar for both lenis and fortis tokens but the intra-oral pressure is almost always higher for the fortis tokens. In addition, the male speakers (CM, DN and TD) have generally higher flow rates as well as higher intra-oral pressure values amongst the fortis stops when compared with the female speakers (BN, DJ and RN). Figure 7.2 shows that there also is more variability for the male speakers. The female speakers have lower overall flow values but the values of lenis and fortis stops are grouped. There are however many outliers including zero values which may indicate some mask leakage. Although there is a general trend, it is not entirely clear that the two groups differ when comparing these parameters.

The results show that peak intra-oral pressure is highly significant in signalling a difference between lenis and fortis medial stops, but peak oral air flow is not a significant indicator of a difference when each of these parameters is investigated separately. To test the interactions between pressure and flow a further linear mixed effects model is constructed. The interaction between Peak U_o and Peak P_o is tested including a fixed factor of stop category, with two factors, lenis and fortis and speaker and token included in the model as random factors ($\chi^2(9, N=210) = 35.6, p < .001$). This shows a significant interaction between Peak U_o and Peak P_o ($p = .012$) at a 95% confidence level although this is not significant at the α used in this study. The effects of pressure on these results was not controlled in the study.

7.3.2 Burst amplitude and intra-oral pressure at the release

This section looks to extend this analysis and pose the question: do stop releases with higher amplitude bursts also have higher peak release pressures? To investigate this, the RMS amplitude is measured at the burst and the corresponding peak P_o within the stop is then measured (see Figure 7.4). The results of the interaction between burst pressure and burst amplitude are shown in Figure 7.5. Differences in relative burst amplitude showed to be significantly different in earlier analyses, discussed § 6.7, with lenis stops found to have a higher relative amplitude when compared with fortis stops. Although this did not correlate with a higher absolute amplitude. The lenis stops often have a low frequency voicing component and this was not controlled for in these experiments. The majority of the lenis stops were fully voiced and consequently the release bursts also had associated voicing underlying.

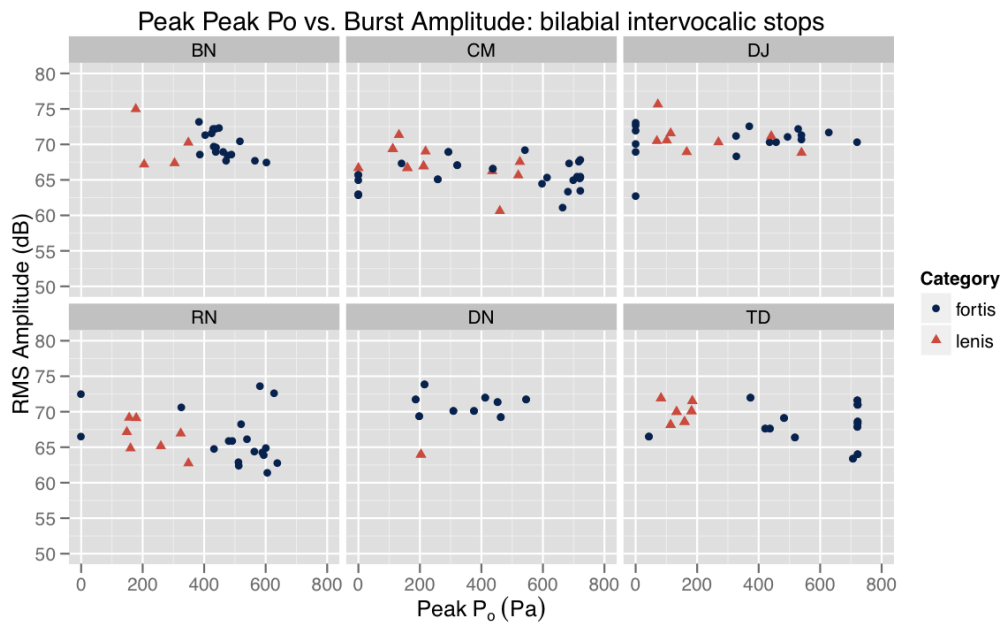


FIGURE 7.4: Peak Intra-oral pressure (P_o Pa) against RMS Amplitude (dB) separated by stop category and by speaker.

Peak oral pressure at the burst and the interaction with burst amplitude of with stop category as a fixed factor and speaker and token as random factors.

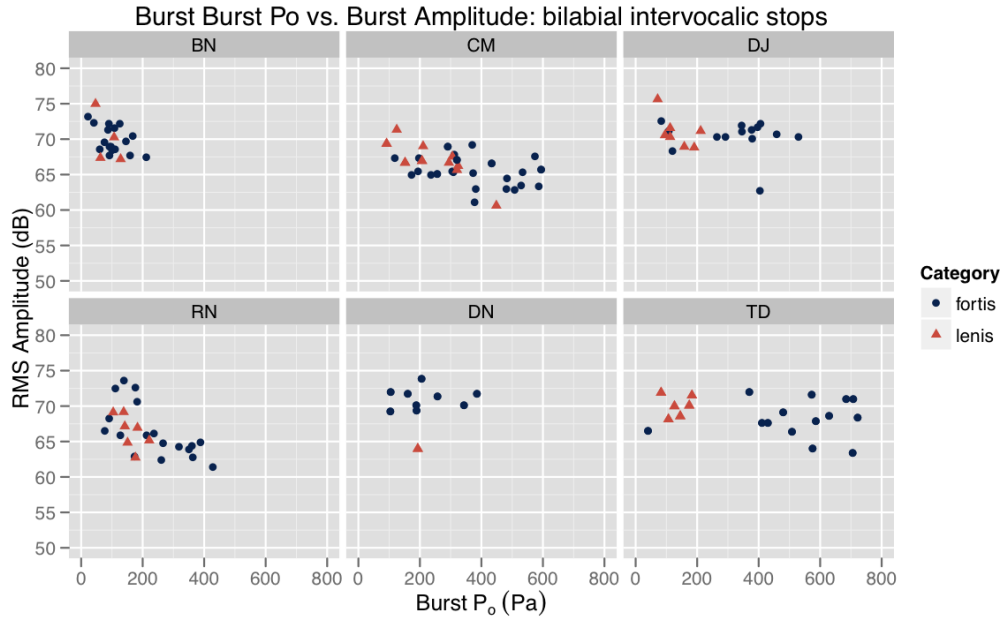


FIGURE 7.5: Peak Intra-oral pressure (P_o Pa) against RMS Amplitude (dB) separated by stop category and by speaker.

The likelihood ratio is significant at a 95% confidence level ($\chi^2(9, N=178) = 15.5, p < .01$) and the difference in the interaction of peak oral burst pressure and burst amplitude is significant ($p < .001$), shown in Figure 7.5. This suggests that a higher burst amplitude correlates with a higher peak intra-oral pressure at the burst. Furthermore it suggests that the two categories have different articulations at the stop release.

As a comparison, oral airflow measured at the burst and compared with RMS amplitude also measured at the burst. There is no obvious correlation between these parameters however (shown in Figure 7.6). In addition, there are no differences found in the airflow between each of the stop categories.

The discussion of U_o will be left here and the topic will be returned to later in this chapter, when the timing of oral flow with respect to vowel onset is investigated in § 7.5.1.

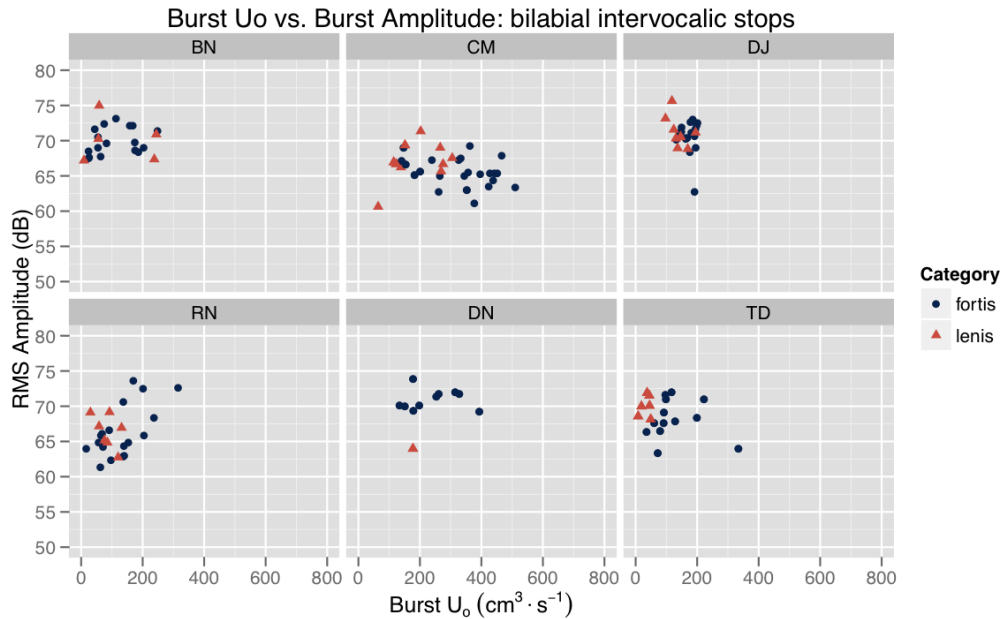


FIGURE 7.6: Peak oral flow (U_o cm³/s) against RMS Amplitude (dB) separated by stop category and by speaker.

7.3.3 Peak pressure vs. consonant duration

Duration and peak intra-oral pressure are the two parameters that have been shown to consistently differentiate between fortis stops and lenis stops. A longer duration also tends to show a corresponding high peak in intra-oral pressure. Based on these results a further hypothesis could be formulated that the intra-oral pressure will rise unimpeded until stop release and that these high peak values are not independent of duration.

In proportional terms, if the entire duration of the consonant is considered, the peak pressure is found 42% into the closure period for fortis stops and 79% into the closure for lenis stops. In absolute terms however, there is no difference in the average time it takes for lenis and fortis stops to reach their peak intra-oral pressure (see Figure 7.7). These results are not conclusive due to inter-speaker variation particularly from speaker CM (see Figure 7.8).

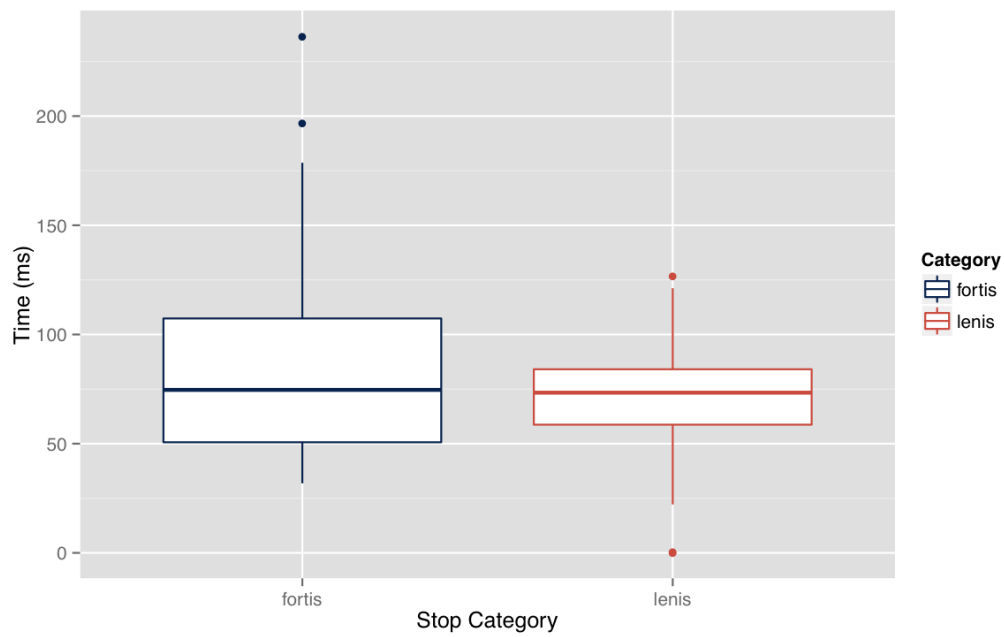


FIGURE 7.7: The time to reach peak intra-oral pressure by stop category.

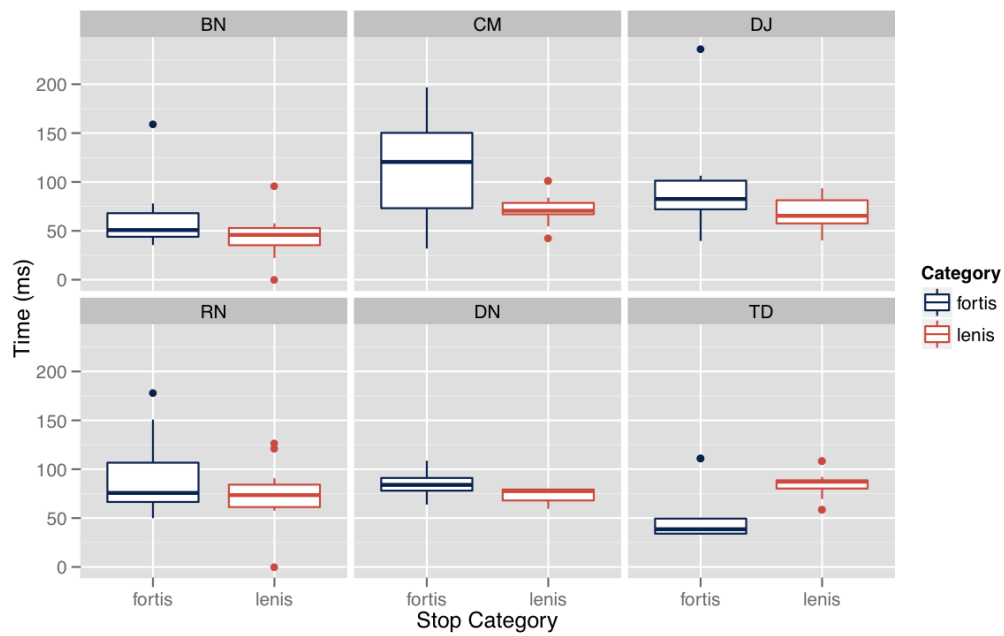


FIGURE 7.8: The time to reach peak intra-oral pressure by stop category and speaker.

The interaction between consonant duration and peak intra-oral pressure for a main effect of stop category is shown to be significant ($p < 0.001$), but as shown above, although the absolute values of peak pressure are higher the time it takes to achieve these pressures is comparable for both lenis and fortis stops. This suggests that the fortis stops have a faster rise-rate than the lenis stops and that they both have different pressure targets as well as differences in duration. This pattern has been described by Butcher (2004, p. 553) for a number of Australian languages. This relationship between pressure and duration will be investigated further in the following section § 7.4 using the pressure impulse measurement described in the methodology (see § 5.7.9).

7.4 The pressure impulse

This section of the experiment uses the pressure impulse measurement as proposed by Malécot (1955, 1966a, 1966b, 1970). This calculation uses the value of intra-oral pressure across the period of stop closure to infer differences between stop categories (see § 5.7.9). The pressure impulse for each medial stop is estimated using both the peak intra-oral pressure P_o and durational measurements for intervocalic medial bilabial stops. The results show that there is a very strong difference in the pressure impulses between lenis and fortis stops.

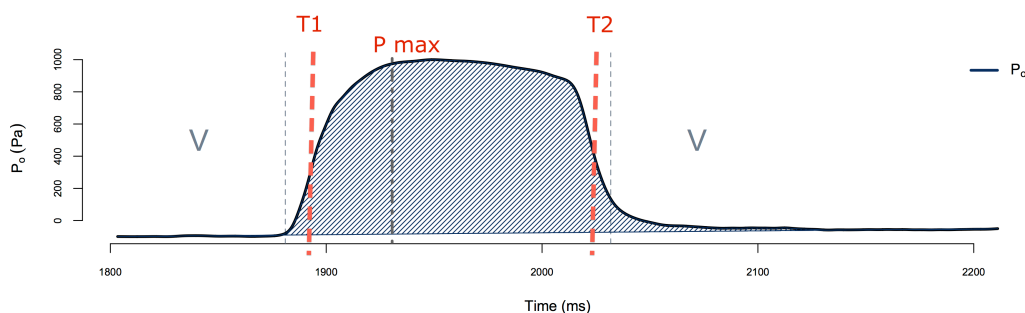


FIGURE 7.9: The area under the intra-oral pressure (P_o) curve (shaded) for an intervocalic fortis stop - The Pressure Impulse.

The limits used in this measurement are shown with dashed lines indicating

the stop closure on the left and the onset of voicing on the right in Figure 7.9. The area under the pressure curve is calculated in order to investigate differences in intra-oral pressure with respect to time.

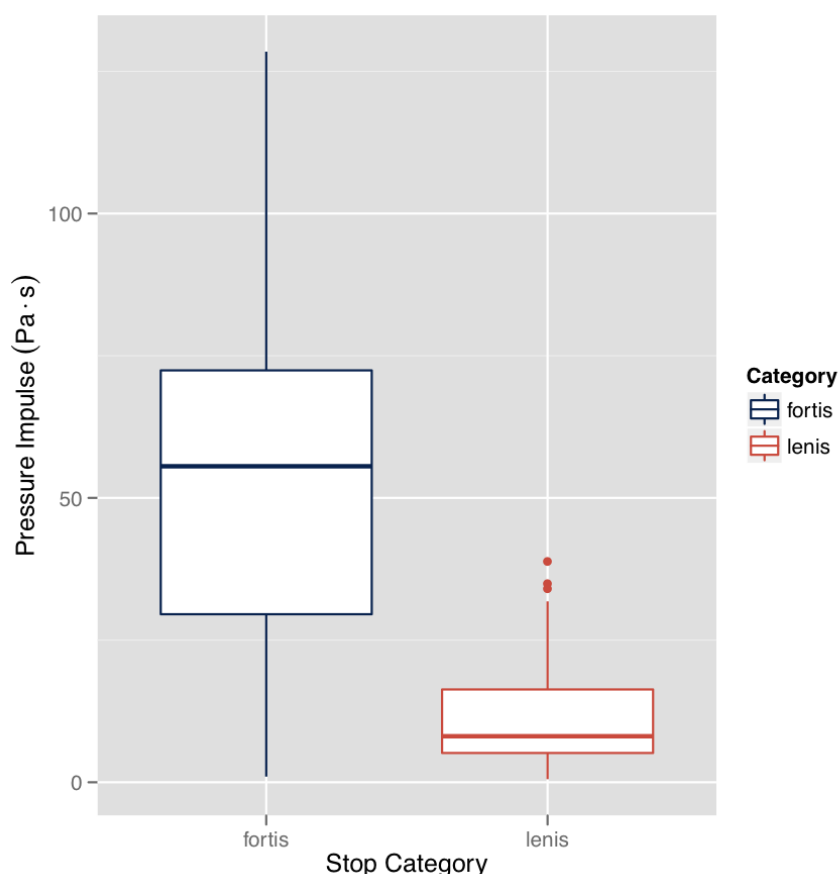


FIGURE 7.10: The differentiated area under the intra-oral pressure curve (Pressure Impulse) separated by lenis and fortis stops (shown in pascal.seconds (Pa.s)).

Figure 7.10 shows that the pressure impulse for fortis stops is much higher than that of lenis stops although there is variability. The increased value for peak pressure over time for fortis stops is a reflection of the greater duration. The lenis stops have a lower peak intra-oral pressure and a shorter duration resulting in radically lower pressure impulse values. Individually each of the speakers shows a difference in fortis and lenis pressure impulse as shown in Figure 7.11. A statistical analysis using LMEM with a significant likelihood ratio ($\chi^2(8, N=194) = 20.2, p < .001$), confirms that there is a significant difference

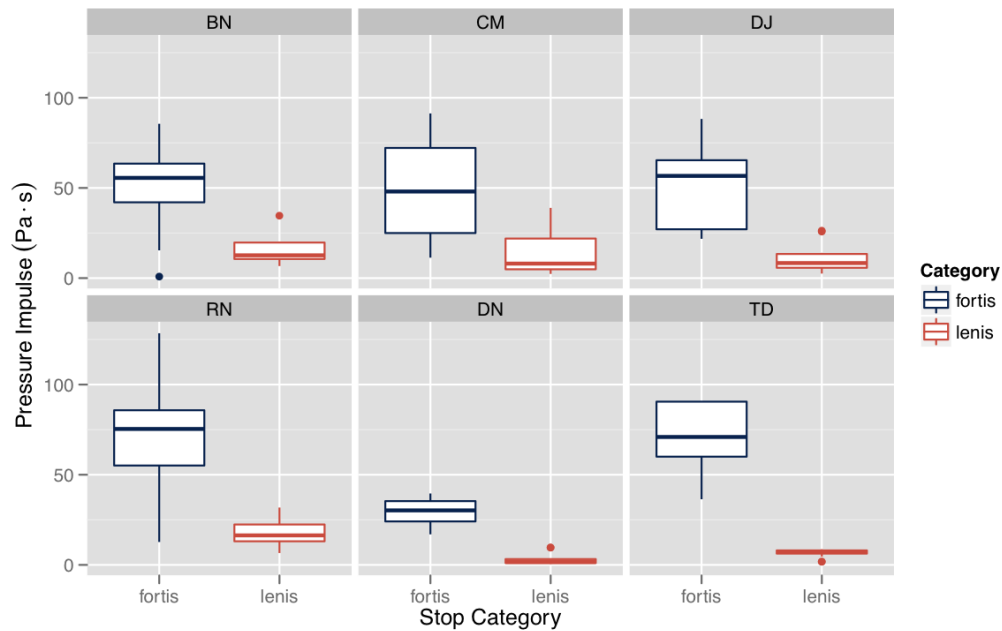


FIGURE 7.11: The differentiated intra-oral pressure curve (Pressure Impulse) separated by lenis and fortis stops and speaker (in pascal.seconds (Pa.s)).

in pressure impulse testing a main effect of stop category (lenis or fortis) as a fixed factor and speaker and token included as random factors ($p < .01$).

7.5 Timing interactions between oral air-flow and intra-oral pressure

This section describes the interaction between oral airflow (U_o) and intra-oral air pressure (P_o) in terms of the timing of the articulators (see § 5.7.10). Due to the complexity of inter-speaker and within-speaker variation in the timing of airflow peaks, a generalised description is thus far elusive. Individual pressure and flow records are presented below in the following sections (§ 7.5.1 and § 7.5.2) showing where there is relative similarity and variation within the data. The figures all display synchronised Laryngographic records (L_x) in the bottom panel of the plot to demonstrate the extent of voicing into the medial

stop. Further Laryngographic results are reported in the following chapter in § 8.6.

7.5.1 Timing of the oral air-flow peak with respect to vowel onset following a medial consonant

Whilst listening to Biniñ Gun-wok utterances and observing the associated oral airflow data (U_o), it has become clear that the timing of the oral airflow peak after the release of the stop and the degree of voicing are somehow related. The precise nature of this relationship is unclear however, which is the motivation for measuring the timing of the oral airflow peak with respect to the vowel onset. A sharp increase in airflow can occur either just after the release of the consonant or very early after the onset of the vowel (V_2). The variation can be seen in Figure 7.12 and Figure 7.13. Although these examples are from different speakers this level of variation can be shown within the same speaker. These figures do not exhaustively show the variation in the sample however. This measurement uses words at all places of articulation.

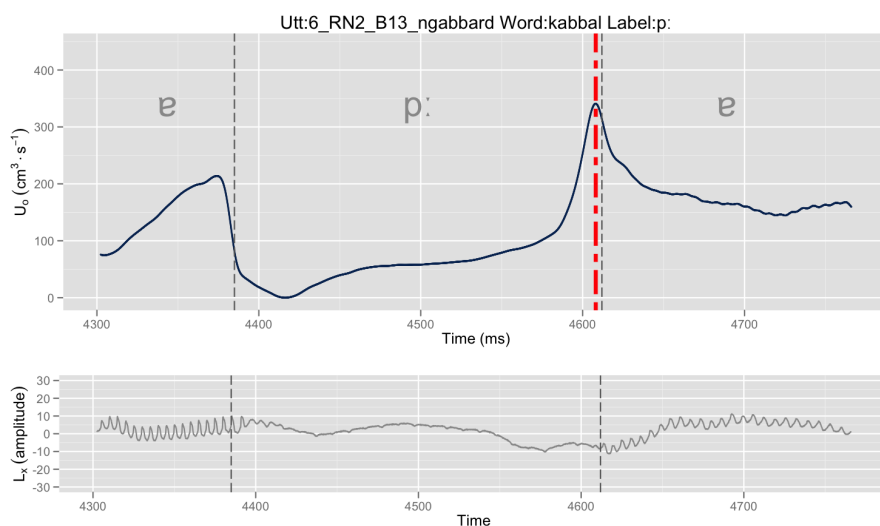


FIGURE 7.12: The peak oral air flow (U_o^{MAX})—marked with the vertical line in red—for a fortis stop in the word *kabbal* – speaker RN.

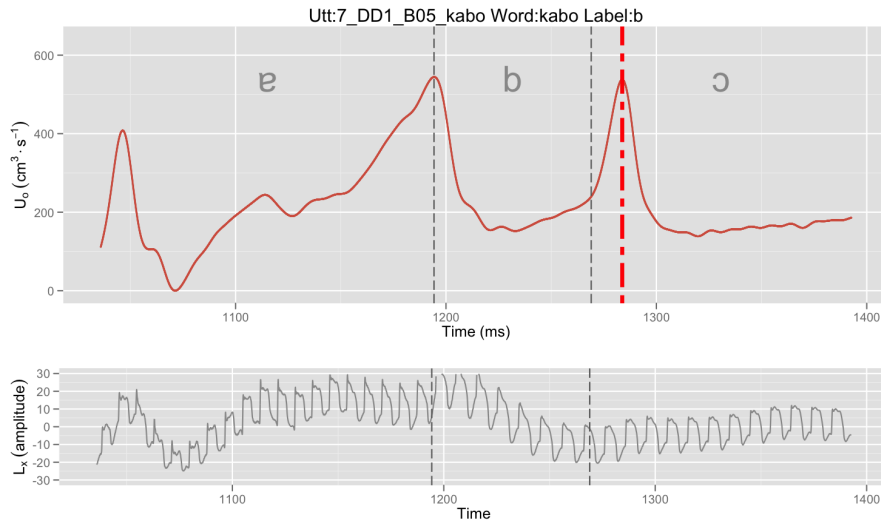


FIGURE 7.13: The peak oral air flow (U_o^{MAX})—marked with the vertical line in red— for a lenis stop in the word *kabo* – speaker DD.

In Figure 7.14 the timing of the peak oral flow with respect to the vowel (V_2) onset is shown, separated by speaker. Each of the speakers differ as to whether the peak is prior to the onset of voicing in the vowel or whether airflow peaks after voicing has commenced. Despite this variation, each of the speakers regularly delays the peak oral air flow for the lenis stop compared with the fortis stop. The airflow peak for the fortis stop can be just after the release or coincident with the onset of the vowel. It is thought that the differences may be place of articulation dependent. When testing this hypothesis statistically, a main effect of stop category on ΔU_o^{MAX} does not prove to be statistically significant, when speaker and token included as random factors and a likelihood ratio test performed ($\chi^2(5, N=210) = 0.9, p = .34$). Furthermore, when the effect of place of articulation on ΔU_o^{MAX} is included in the model as a fixed factor, the result of the LMEM was also not significant.

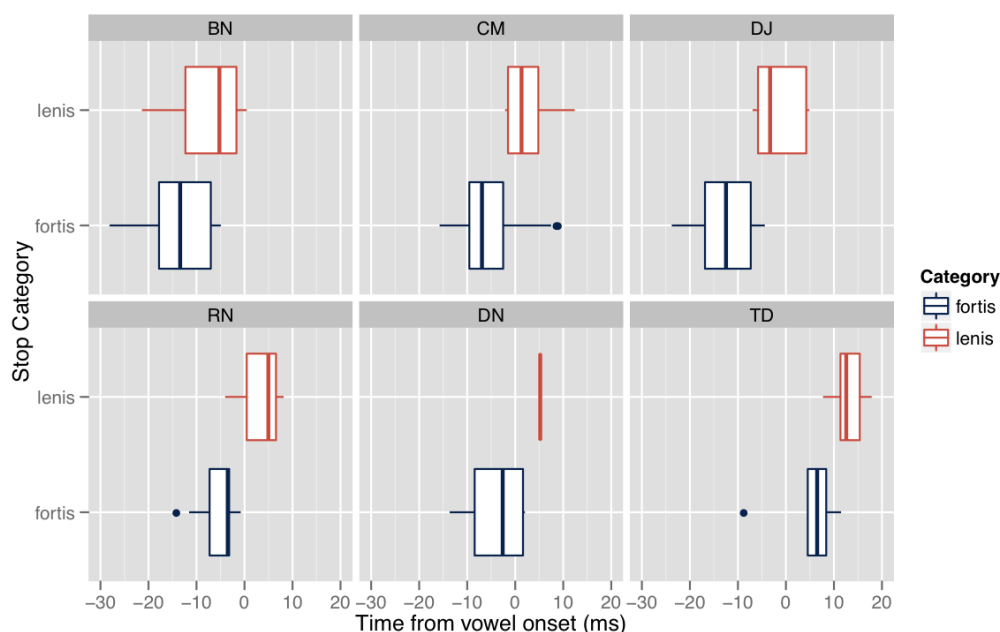


FIGURE 7.14: *Timing of Oral flow peak with respect to the vowel onset (ΔU_o^{MAX}).*

7.5.2 Oral air-flow in vowels preceding medial consonants

As well as airflow peaks associated with the release of oral stops and the transition into of V_2 , there are also airflow changes evident in the transition from V_1 into the medial consonant. Referring back to the aims for this experiment (§ 7.1), the second aim is to investigate whether there is evidence of passive or active devoicing and the different strategies required for the phonetic realisation of fortis stops in particular. As discussed in § 5.7.10, the variable nature of these data make it difficult to generalise and quantify the differences. Due to these limitations individual tokens are separated out and shown below. In the figures, a V_1CV_2 sequence is shown in order to provide the environmental context. The corresponding pressure (P_o) and Laryngographic (L_x) records are also provided showing the laryngeal activity and provides information about the extent of voicing into the medial stops.

Figure 7.15 is an example of a medial bilabial fortis stop and as a comparison

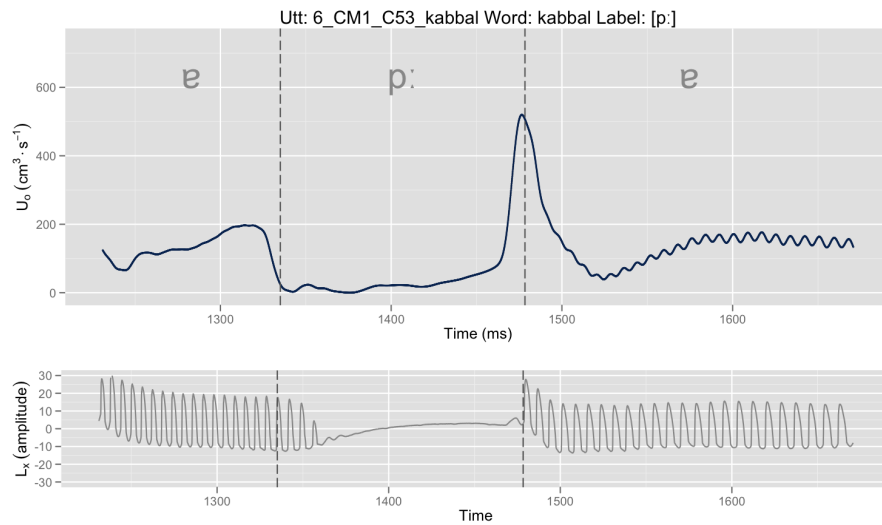


FIGURE 7.15: Oral Airflow (U_o) and Glottal Activity (L_x) for a bilabial fortis stop kabbal 'flood plain' for speaker CM.

the same word is shown for a different speaker in Figure 7.16. In Figure 7.15, the oral airflow in V_1 rises gently prior to full closure but drops off before the closure is complete. Figure 7.16 shows a similar airflow rise in the V_1 at approximately 1750 ms but the U_o drop is delayed until after the closure just prior to 1800 ms. These variations may be due to limitations in the labelling criteria as the boundaries are labelled with reference to the acoustic signals rather than the articulatory data so they are consistent with the acoustic-only recordings reported in Chapter 5.

The lenis stops shown in Figure 7.17, Figure 7.18 and Figure 7.19, do not show the same rise in airflow in V_1 , and the voicing extends throughout the closure period. This may indicate that there is not a glottal abduction gesture in V_1 prior to stop closure. When there is a clear airflow peak that is unimpeded by oral constriction there is very little difference between the stop categories (see § 7.3.1). In Figure 7.16 the peak oral airflow is above $600 \text{ cm}^3/\text{s}$ and a similar value is shown for airflow release in the lenis (Figure 7.18).

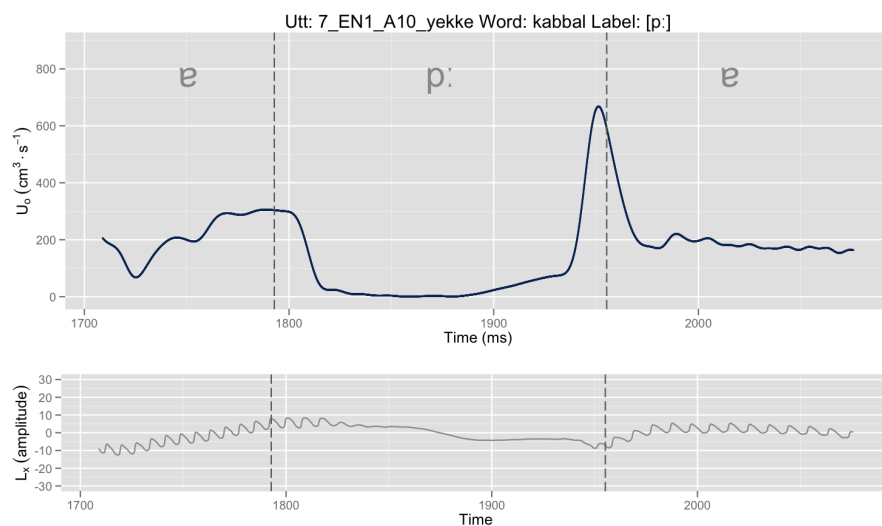


FIGURE 7.16: Oral airflow (U_o) and glottal activity (L_x) for a bilabial fortis stop kabbal 'flood plain' for speaker EN.

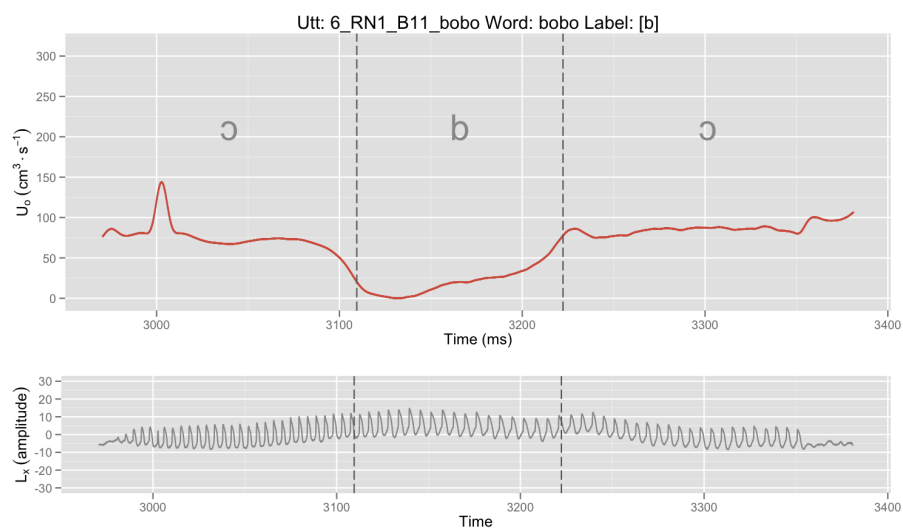


FIGURE 7.17: Oral airflow (U_o) and glottal activity (L_x) for a bilabial lenis stop bobo 'goodbye' for speaker RN.

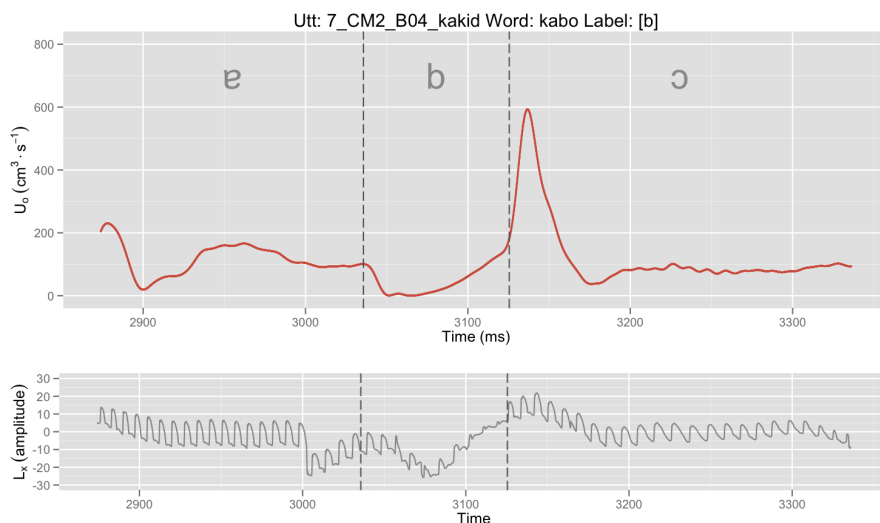


FIGURE 7.18: Oral airflow (U_o) and glottal activity (L_x) for a bilabial lenis stop *kabo* ‘green ant’ for speaker CM.

The discontinuity evident in Figure 7.18 at around 3000 ms shows unexplained glottal activity and the glottal pulsing does not continue modally throughout the entire consonant unlike the other examples shown here (Figures 7.17, 7.19 and 7.20). This example does not appear to be hyper-articulated, although it is in the token 2 position of the carrier phrase and consequently phrase final.

The airflow rise is also absent at other places of articulation as well as in bilabials. Figure 7.20 shows a medial lenis palatal stop which, in addition to no rise, shows a sharp dip in the airflow at the consonant onset. This indicates only a very brief period of full closure followed by a release that does not have tight oral closure. The activity in oral cavity does not affect the laryngeal function however, and voicing continues throughout the stop closure.

7.6 Discussion

This results of this experiment show that there are articulatory differences between lenis and fortis stops and that these differences can be characterised as

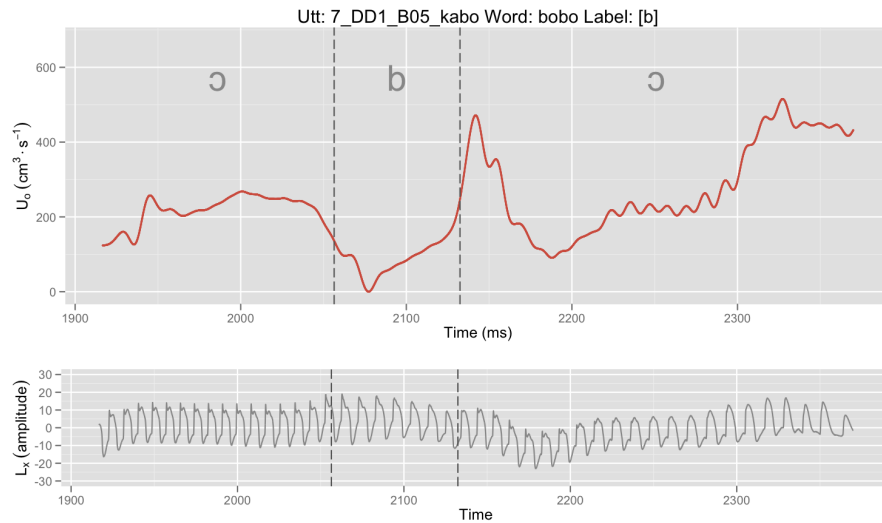


FIGURE 7.19: Oral airflow (U_o) and glottal activity (L_x) for a bilabial lenis stop bobo ‘goodbye’ for speaker DD.

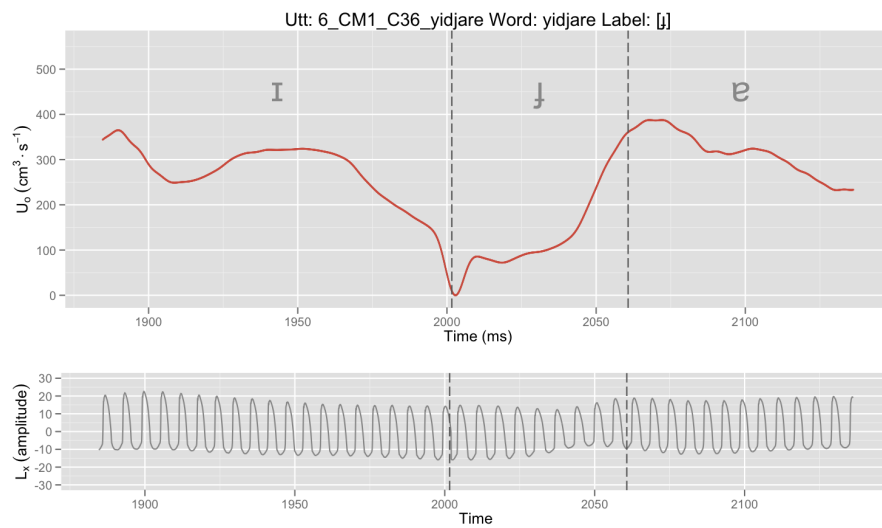


FIGURE 7.20: Oral airflow (U_o) and glottal activity (L_x) for a palatal lenis stop yidjare ‘you want’ for speaker CM.

one of strength or force of articulation. Considering each of the aerodynamic measurements, the results show that an increase in intra-oral pressure (P_o) does not produce an associated increase in peak oral airflow (U_o) however, either at or after the stop release.

The peak oral-flow measured at or just after the release is similar and cannot be used to differentiate between the two stop categories. This is in contrast to other languages described, for example German (Butcher, 1977) and English (Klatt, Stevens, & Mead, 1968) that have fortis stops with a higher airflow at the release than lenis stops (see § 7.3.1). This suggests that respiratory effort based on greater pulmonic energy does not signal a difference between the stop categories. This may call into question the assignment of the lenis and fortis labels. Continuing the discussion of airflow, the vowel preceding the medial stops (V_1) do not show a difference in overall oral flow although there are some localised peaks at the offset before closure in fortis stops (see § 7.5.1). Testing an hypothesis that fortis stops are actively devoiced and the lenis stops are passively devoiced. An associated rise in the airflow is expected, indicating a glottal abduction gesture. Butcher (forthcoming) has found a rise in airflow that precedes long (fortis) stops in Gupapuyngu. Bininj Gun-wok does not consistently follow this pattern, however.

In related oral flow measures (§ 7.3.1), when the male speakers have an increase in oral airflow (U_o) this does not correlate with a higher intra-oral pressure (P_o) for lenis stops. Both the maximum flow rates (U_o^{MAX}) and the peak pressure (P_o^{MAX}) were higher in fortis stops, indicating that the glottis may have an abduction at the point of release. For the female speakers the peak intra-oral pressure (P_o^{MAX}) was significantly different between lenis and fortis but this difference was not evident in peak oral airflow (U_o^{MAX}).

There is a correlation between burst amplitude and peak intra-oral pressure at the release (P_o^{MAX}) but none found between burst amplitude and maximum oral airflow (U_o^{MAX}) (see § 7.3.2). As discussed in § 4.4 on the phonetics of

Bininj Gun-wok there is a prevalence of approximation amongst the lenis stops. Jaeger (1983, p. 187) makes reference to these lenited articulations in Jawoyn and says that these allophonic realisations are related to timing rather than an intrinsic ‘laxness’. For many speakers of Bininj Gun-wok the lips do not make a tight closure in a lenis bilabial stop. If there is loose closure of the lips then a higher pulmonic pressure is enough to force air through the lips creating frication or an approximated stop. This in turn registers a low or non-existent intra-oral pressure despite the higher amplitude at the release—which is equivalent to a burst in the majority of lenis stops. This suggests that higher pulmonic pressures do not always correlate with higher intra-oral pressures. The fortis stops on the other hand show a higher intra-oral pressure and for the conditions to be met for this to occur there needs to be tight oral closure. This idea of sensory looping agrees with Malécot’s observations that some form of synaesthetic, or proprioceptive feedback is necessary in the articulation of a fortis stop (Malécot, 1970, p. 1591).

Feedback is, by definition, circular and the closed system relies on perception as well as production. The importance of this feedback in the separation of the stop categories cannot be resolved until all the parameters involved in the articulations of these stops are described. The timing of a rise in intra-oral pressure and the degree to which the pressure rises may cue a difference for a speaker.

7.6.1 Intra-oral pressure as independent of duration

The results of the pressure impulse measurements show a clear difference in pressure impulse between lenis and fortis stops, confirmed statistically for all speakers measured (§ 7.4).

There has, however, been previous debate as to whether intra-oral pressure is in fact independent of duration. Jaeger (1983) argues that oral pressure is not an independently controlled variable. The pressure impulse measurement

does not measure pressure independent of duration, but it does show that when duration is kept constant there is a difference in the overall pressure regardless of a high maximum peak intra-oral pressure (P_o^{MAX}).

As introduced in the previous section, Malécot (1970) cited by Jaeger (1983, p. 186) contends that the force of articulation found in fortis stops is due to a synaesthetic feedback that is a direct result of complete closure in the vocal tract. Bininj Gun-wok stops fortis stops are highly stable in their articulation. On one hand, in fortis stops a tight closure is a prerequisite for the rise in intra-oral pressure and which in turn extinguishes voicing. In lenis stops on the other hand the associated tight closure in the occlusion is variable and not always present evidenced by the prevalence of approximation and frication. Voicing is also prolonged and there is not an associated pressure rise.

The timing of peak pressure in both lenis and fortis stops suggests that there is a timing target that is consistent for each stop category. The maximum intra-oral pressure (P_o^{MAX}) is attained at a similar time after closure for both lenis and fortis stops. The fortis stop data however, seems to indicate that there is a more rapid rise in the intra-oral pressure with peak pressures often 2–3 times greater than that of lenis stops. This is presumably a result of high volumes of air flowing through the glottis and tight closure at the lips. The delays in the oral airflow peaks—for example the delay in lenis stops—show that the glottis may be held in an adducted position ready for voicing at or very soon after release in both stop categories (§ 7.5.1). This hypothesis is confirmed by the very short VOTs measured (as discussed in § 6.9.2). This suggests that it is not only duration that provides the conditions for voicelessness shown in fortis stops, it is also force of articulation of articulatory closure rather than in the pulmonic system.

7.6.2 Relative timing of air-flow peaks

The relative timing of the airflow peaks show the same patterns in all speakers although the timing with respect to the onset of voicing varies.

For some speakers the lenis stops has the peak after the onset of voicing into the vowel and the fortis stops the peak oral flow just after the release of the articulators and before the onset of voicing in the VOT period. In addition, some speakers consistently delay the airflow peak until after the onset of voicing as shown in Figure 7.21. The VOT in this case is very short, but this delay also occurs at the other places of articulation.

As discussed above, the speakers of Bininj Gun-wok recorded as part of this study tend to delay the airflow peak until after the release of the articulators and the onset of voicing. This gives an auditory percept of a voiced stop even when the airflow peak is well into a vowel following a voiceless, long closure.

This observation has been shown after both fortis and lenis stops although the airflow peaks are far more prevalent following lenis stops. These delayed airflow peaks are also observed more often in speakers with a faster speech rate although no information on speech rate has been explicitly reported. Relatedly, the speakers with a fast speech rate also speak with much higher intensity (loudness) with greater overall aerodynamic range.

These airflow peaks that occur after closure are reminiscent of the peak in airflow found at the release in the aspirated consonants found in languages such as English (Klatt et al., 1968; Subtelny et al., 1966) or lenis stops in Korean (see Figure 3. in Dart (1987, p. 140) for speaker 6). Korean aspirated stops show far higher airflow peaks prior to the onset of voicing. The neither fortis or released lenis stops Bininj Gun-wok are aspirated and both have very short VOTs. In these respects they pattern closely with Korean lenis stops in terms of release characteristics.

Airflow in the vowel preceding a stop (V_1) often shows a gentle rise prior to closure in both lenis and fortis stops. This airflow rise is nowhere near the

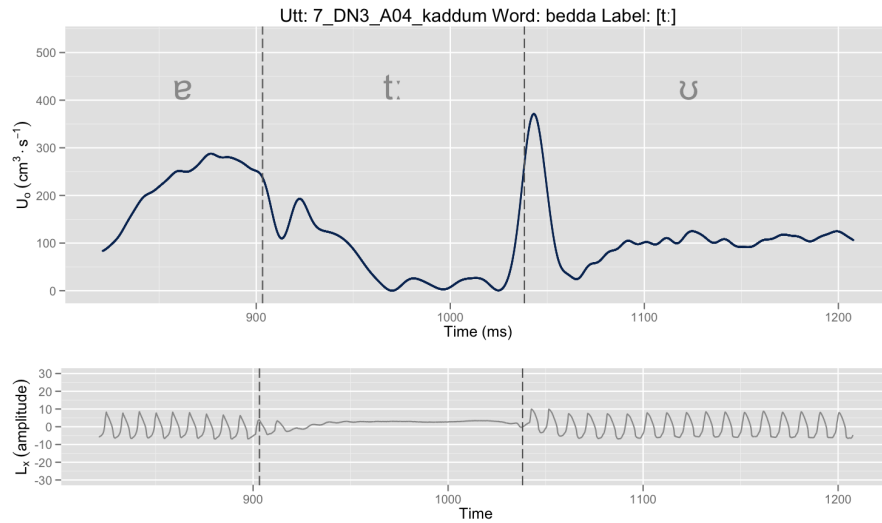


FIGURE 7.21: A medial apical fortis stop in the word *kaddum* ‘above’ for speaker DD.

magnitude of that found at the stop release. Sharper airflow rises are more prevalent in the vowel preceding fortis stops, but due to the extreme variation in the timing and magnitude of the peaks this has been difficult to quantify in this study. The fact that the observed rise is not rapid suggests that there is not an associated glottal abduction gesture timed with the supra-laryngeal closure. The rises in airflow are not sufficient to extinguish voicing by themselves. This suggests that as there is no associated glottal abduction gesture preceding the stop closure, actively devoicing the following stop.

Both lenis and fortis stops are potentially passively devoiced, but the actual articulatory mechanisms that lead to this devoicing is dependent on tight oral occlusion—for example at the lips in bilabials. Following tight closure is an associated rise in intra-oral pressure, creating a trans-glottal pressure differential insufficient for voicing to continue. In lenis stops there is either incomplete closure of the articulators resulting in a phonetic fricative or approximant or if tight closure does occur the voicing is can be continued by passive expansion of the vocal tract. The resulting rise in intra-oral pressure is less and the maxi-

mum is also less when compared to a fortis stop. In this respect pressure rises and the patterns of voicing are interconnected.

7.6.3 Concluding remarks

As reported in the previous chapter, there is a measurable difference in length between medial lenis and fortis medial stops. In this chapter, a difference in strength was measured, not only in terms of closure duration but also an increase in the articulatory force. This conclusion is reached primarily because the intra-oral pressure does not rise indefinitely depending on the stop duration and reaches a peak pressure at a similar time after closure as lenis stops.

The pressure impulse shows that there is a difference in terms of duration and intra-oral pressure. In order for the conditions to be met and for the oral pressure to rise, there needs to be tight supra-glottal closure and control of airflow through the glottis.

Butcher (2004) argues for a rescaling hypothesis in the subset of Australian languages that have two stop series. Lenis and fortis stops have different target pressures (Harrington, Fletcher, & Roberts, 1995). The evidence for this comes from the fact that the intra-oral pressure is not dependent on the stop duration and does not rise indefinitely. The peak pressure values are attained at similar times for lenis and fortis stops, yet the peak pressure values are far higher for fortis stops. Butcher says for a related language that “[t]his would seem to indicate that, in Burarra at least, control of glottal aperture and articulatory stricture formation are the main parameters underlying the distinctive variation in peak intra-oral pressure” (Butcher, 2004). The results for Bininj Gun-wok largely agree with Butcher’s (2004) observations regarding lenis and fortis stops in Australian languages which show that there is a difference in the strength of articulation but that this difference is one that is dependent on both duration and peak pressure.

The results presented in this chapter do not prove that intra-oral pressure

is independent of duration. When peak pressure and duration are combined into a single parameter—the pressure impulse—there is a reliable phonetic difference between lenis and fortis stops. The following chapter investigates the differences observed within long stops to see if there is a difference between fortis stops and geminates. This also look at whether pressure and duration are independent when duration is kept constant.

Chapter 8

Geminates, clusters and medial voicing

This chapter looks briefly at the phonetic differences between fortis stops and clusters. The previous chapters have shown that there is a difference between lenis and fortis stops in terms of length and intra-oral pressure. Clusters of oral stops that are both homorganic and inter-morphemic are described as impressionistically different to fortis stops (see § 1.3.3). It has been a matter of debate whether there is a phonetic difference between fortis and geminate stops in other languages. Are geminates more like a single unit in Bininj Gun-wok like fortis stops or are they realised more akin to clusters? In this analysis fortis stops are compared with both homorganic and heterorganic clusters in terms of duration. The primary aim is to investigate the phonetic differences between fortis stops and geminates. A secondary aim of this chapter is to look at differences in voicing between lenis, fortis and geminates making use of durational measurements in addition to the aerodynamic measurements developed for the previous chapter. This chapter is an extension of the analysis found in the previous two chapters and follows the methodology closely, with some additional aspects that are listed below.

8.1 Method

The overall methodology for this chapter is detailed in Chapter 5. Specifically, see § 5.7.1 for details on the aerodynamic recording techniques and see § 5.8, for the analysis of voicing. The specific methods are elaborated on below.

8.1.1 Aims

The aims of this chapter are:

- i. To measure cluster durations so as to compare their durations with geminates.
- ii. To investigate any differences between fortis and geminates and how this impacts the phonological analysis of Bininj Gun-Wok stops.
- iii. To conduct a voicing analysis of medial consonants investigating the effects of passive or active voicing/devoicing. This uses a combination of acoustics and electroglottography in order to investigate how the aerodynamic system influences and is affected by the laryngeal settings found at the onset and release of medial stop closures.

The aims are related to the variation observed within word-medial phonetically long segments. This included fortis stops which are always within a morpheme and homorganic geminate clusters which span a morpheme boundary. As discussed above (§ 2.2), the use of the term geminate is problematic, but geminate is used in favour of “false-geminates” to simplify the discussion.

8.1.2 Speakers

The durational analysis of cluster durations is taken from a sample of five speakers drawn exclusively from Corpus I. These five speakers include three males (HK, OK and DK) and two females (MM, JM). This sample is used because it

has more examples from multiple places of articulation rather than focussing on bilabials

A further sample from Corpus II with nine speakers (BN, CJ, CL, CM, DJ, EN, RN, TD and VB) is used to compare the durations of lenis, fortis, intra-morphemic clusters (geminate) and inter-morphemic clusters (clusters). These are all measurements taken at the bilabial place of articulation. The acoustic voice analysis also uses Corpus I.

Of the nineteen speakers recorded with aerodynamics, a subset of six speakers, three males (CM, TD, DM) and three females (BN, RN, MN) is used in the aerodynamic analysis. This subset has the most complete set of repetitions due to a minimisation of background noise, environmental factors (wind gusts) and speech errors. All these data are taken from Corpus II (See Appendix B.2 for the full list of words).

The physiological voice analysis—which includes the electroglottographic (EGG) data—contains five speakers, four male (CM, DD, DM, EN) and one female (RN) and this is also drawn from Corpus II. In the course of gathering the EGG recordings, two speakers one male and one female were initially recorded as part of a pilot study and subsequently the same speakers were recorded again with an additional three speakers in the following year. The entire word list was not recorded for all speakers however due and there are many missing tokens. Consequently the included tokens focus on the lenis/fortis and fortis/geminate analyses.

A number of difficulties were found in the course of recording the electroglottographic (L_x) data. The cervical morphology of many female speakers in the study made this technique unsuitable. Being unable to locate the laryngeal structures for these speakers made it difficult to properly place the Laryngograph electrodes and consequently obtain a usable signal. It was however, possible to register signals of a suitable amplitude from the majority of male speakers.

8.1.3 Stimuli

The word list for the lenis/fortis analysis has already been presented in the previous chapter in Table 7.1 found in § 7.2.2. This list was then supplemented by words shown in Table 8.1.

TABLE 8.1: *Word list - Aerodynamic: Geminates.*

CAT.	ID	WORD	STRUC.	PHONETIC	GLOSS
GEMINATE					
	C01	kebbaldjurri	VCCV	[kɛ'p:ɐl̩,corɪ:]	<i>royal spoon bill (Platalea regia)</i>
	C02	kebbalhmeng	VCCV	[kɛ'p:ɐl̩ʔ,mɛŋ]	<i>close your nose</i>
	C03	kebbberrelh	VCCV	['kɛp:ɛrɐl̩ʔ]	<i>flat nose</i>
	B01	bakbakkeng	VCCV	[bəkpe'k:ɛŋ]	<i>break into pieces</i>
	D03	nakukkimuk	VCCV	[nɛ'gokɪ,muk]	<i>big man</i>
	D04	kukkimuk	VCCV	['gokɪ:muk]	<i>very big</i>

8.2 Geminates and long stops

8.2.1 Clusters

The duration of stops in clusters is measured and presented in Figure 8.1. As can be seen in Figure 8.1, the overall duration of the clusters is highly speaker specific. What is evident however, is that place of articulation does not play a large role in the absolute durations of the clusters regardless of the place of articulation of C_1 or C_2 . There are 108 tokens included in the analysis.

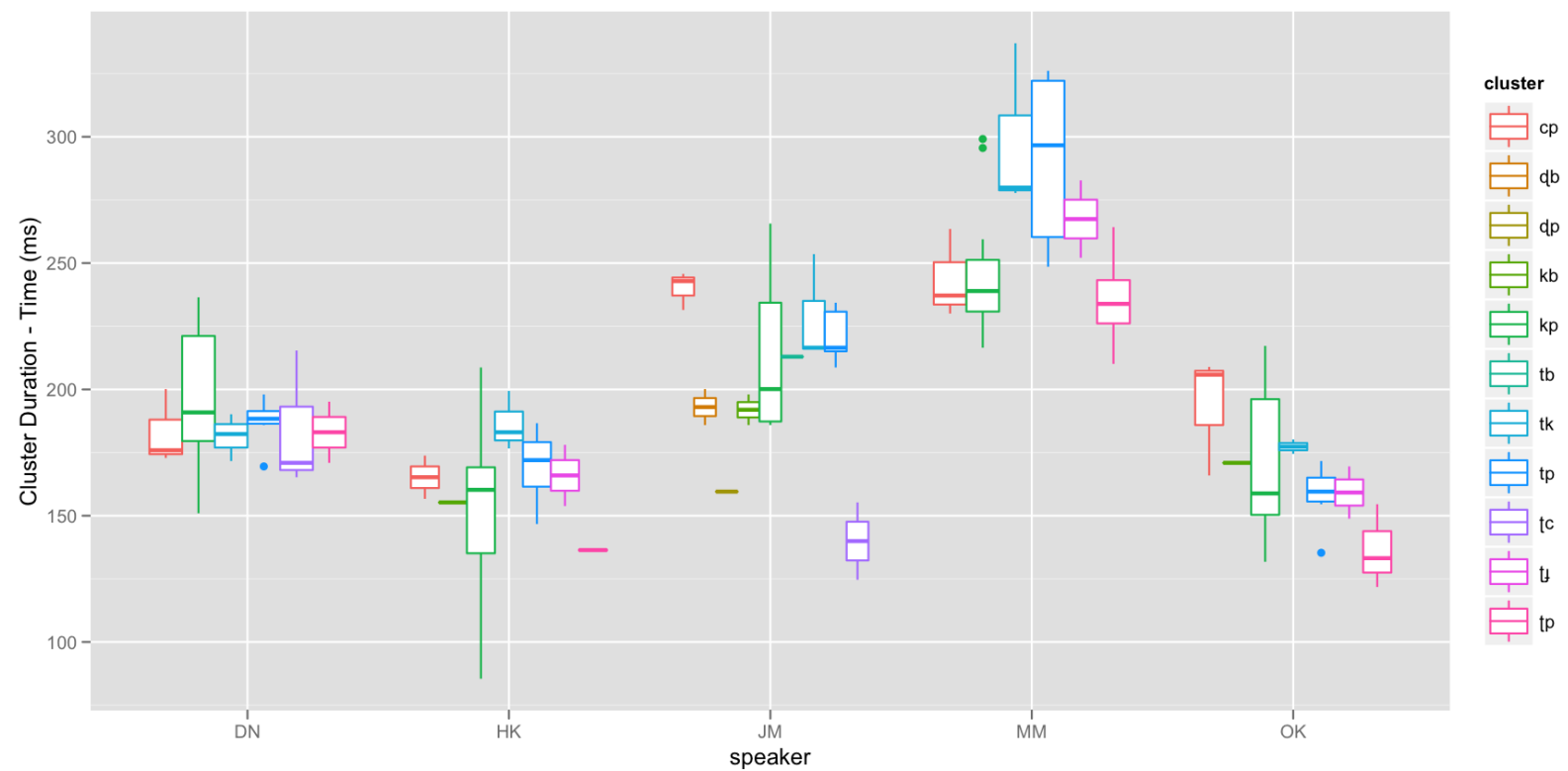


FIGURE 8.1: Medial cluster durations by speaker, Corpus I.

8.2.2 Geminates and clusters

From the results of the acoustic and durational analysis in Chapter 6 a difference between the durations of lenis and fortis stops has been shown. In this section the durations are reanalysed by adding geminates and clusters to the analysis. In Figure 8.2 a box plot shows that there is no apparent difference between geminated clusters and fortis stop. In addition the figure shows that a heterorganic cluster patterns with the geminate and the fortis stop for duration.

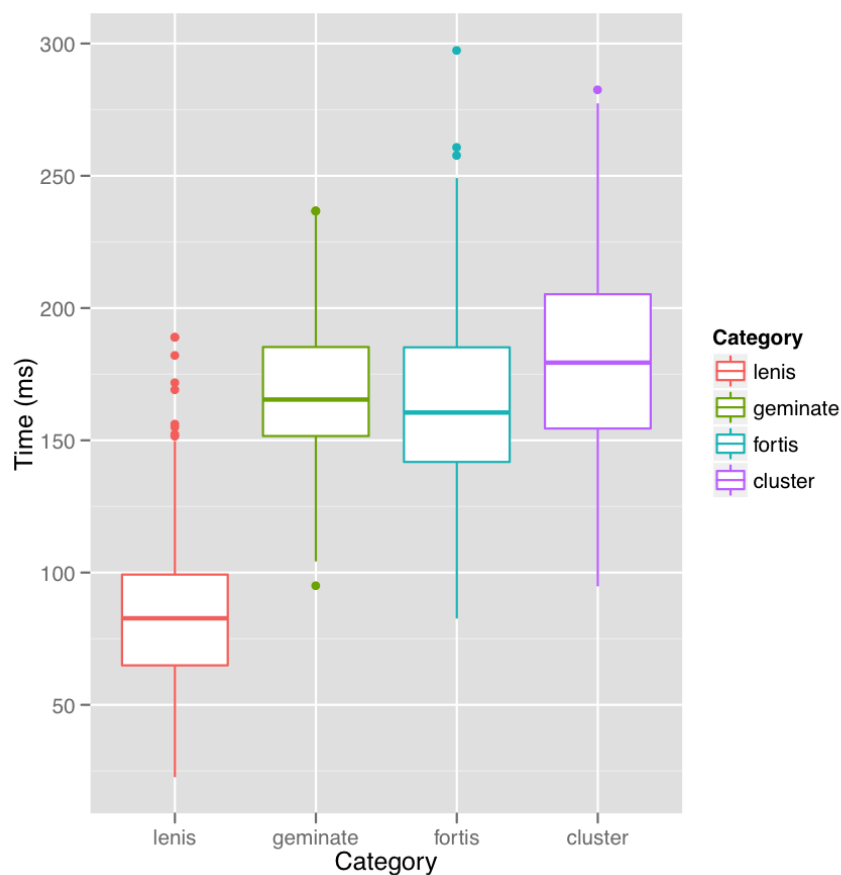


FIGURE 8.2: *Lenis, Geminate and Fortis stops, Corpus II.*

When speaker identity is also taken into account there are some differences between the categories (Figure 8.3). This is confirmed by a statistical analysis. When examining a main effect stop category on cluster duration a LMEM with stop category as a fixed effect and speaker and token as random effects is

constructed. The results of the model show that geminates are not significantly different in duration to fortis stops ($p = 0.65$). Geminates do, however, have a significantly different duration when compared to homorganic clusters ($p < 0.001$). The lenis categories remains statistically different to fortis stops ($p < 0.001$) and is also significantly different in duration to geminates ($p < 0.001$) and homorganic clusters ($p < 0.001$).

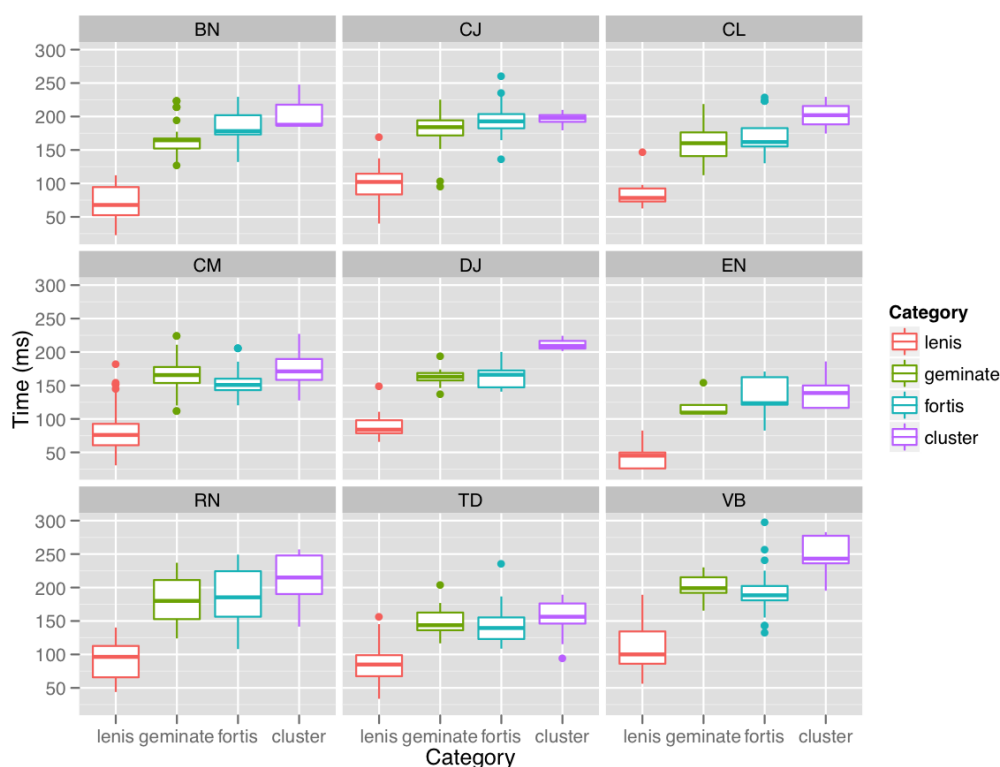


FIGURE 8.3: *Lenis, Geminate and Fortis stops, Corpus II.*

8.3 Final stops

As a comparison to medial stops and cluster durations, the final stop durations are measured. Final stops are particularly interesting as they are often very long in duration (> 75 ms). As shown in Figure 8.4 there are some stops that have been labelled as long stops due to their similarity to fortis stops in both

duration and release characteristics. In this analysis, tokens from Corpus II are analysed as they are embedded in a carrier phrase (see § 6.3 and § 5.2.1).

Final velar stops in particular have a period of voicelessness and a clear aspiration when released. They are often labelled as unreleased due to the long duration of the voicelessness. Aerodynamic measurements have shown that the release characteristics of these final stops shows very high volumes of nasal airflow and this is similar to the effect observed by Carroll (1976) and Schebeck (n.d., 2001), also in Kunwinjku speakers (see § 4.1).

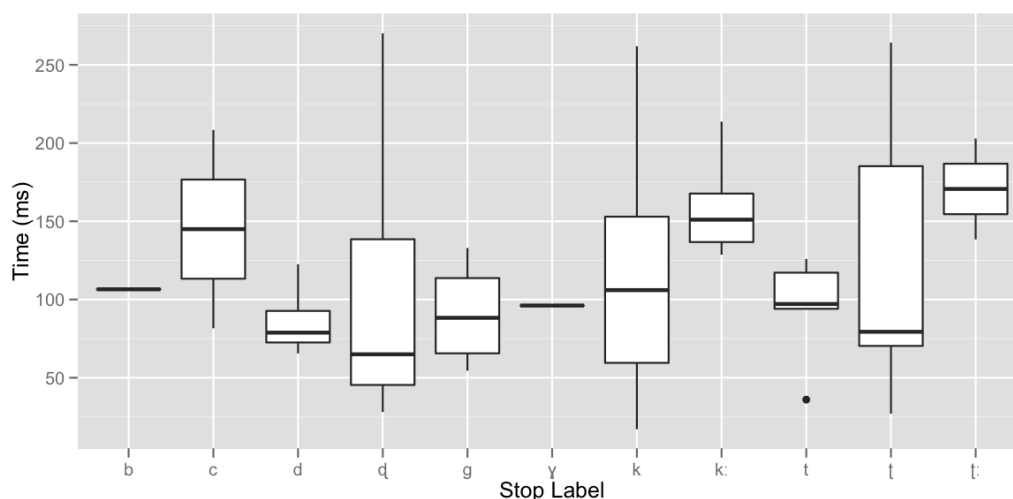


FIGURE 8.4: *Duration of final stops, Corpus II.*

The final stops in focussed position are in medial position within the carrier phrase at the end of an intonational unit. As shown in Figure 8.4 the majority of final stops have duration that is greater than 50 ms. When comparing final stops to word medial stops they are shown to have durations that fall between lenis and fortis stops.

8.4 Aerodynamics

8.4.1 Gemimates as inter-morphemic stop clusters

The measurement of peak intra-oral pressure has been shown in the previous chapter to reliably show a difference between lenis and fortis stops. Peak oral flow does not reliably signal a difference, however. Observationally Peak intra-oral pressure is not a reliable indicator of a difference between fortis and geminates (see Figures 8.5 and 8.6). Peak oral pressure in geminate stops can be equal or greater than peak-intra-oral pressure in fortis stops. Impressionistic observations are that there are different peak-intra-oral pressure patterns suggesting a difference. The failure to find consistent phonetic cue may be due to the variable nature of all clusters in the language coupled with a high level of inter-speaker variation. Some examples of differences in fortis and geminate stops are shown in Figure 8.5 which shows a medial fortis stop and 8.6 which shows a geminate.

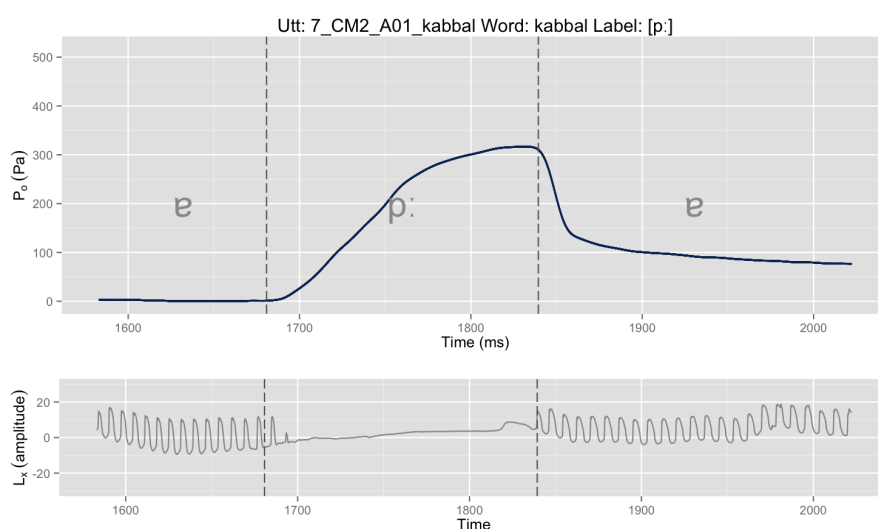


FIGURE 8.5: A medial fortis stop in the word 'kabbal' spoken by CM.

The inter-speaker variation found in the realisation of geminates in terms of non-durational phonetic cues such as intra-oral pressure makes them markedly different to fortis stops however. The fortis stops are highly consistent in their

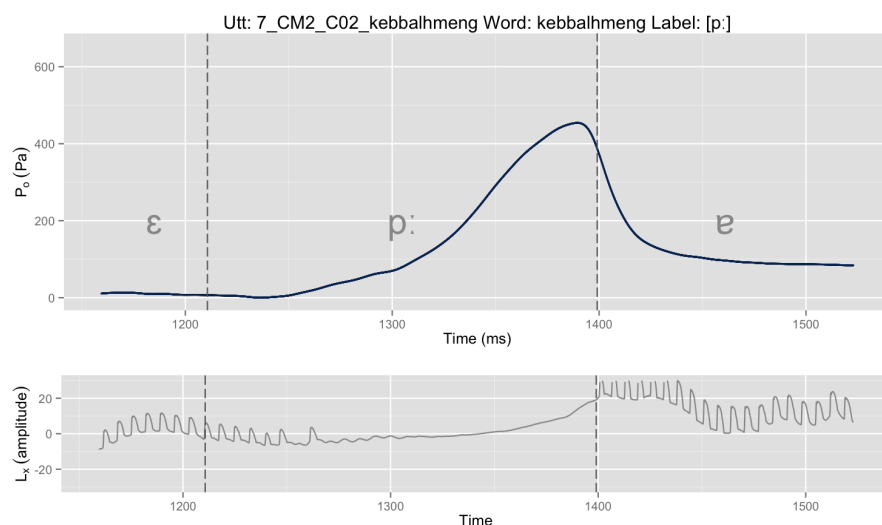


FIGURE 8.6: A medial geminate cluster in the word 'kebbalhmeng' spoken by CM.

realisation whereas the geminate stops are much more variable. Figure 8.7 shows an example of this variability.

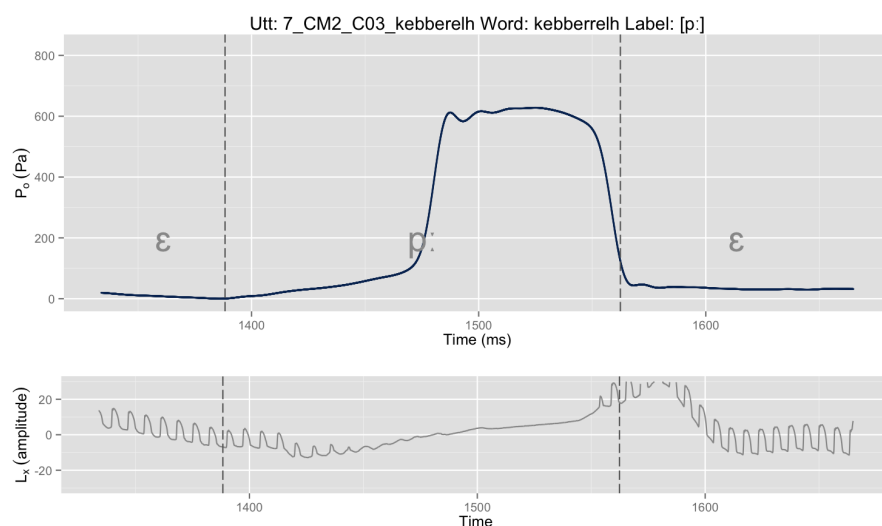


FIGURE 8.7: A medial geminate cluster in the word 'kebbberelh' spoken by CM.

The important this to note is that in addition to these words having different numbers of syllables they also have different stress assignment. The word *kebbalhmeng* [kɛ'p:ɛlʔmɛŋ] 'close your nose!' has stress assigned to the second

syllable of the word, whereas *kebberelh* [ˈkɛp:ɛɪɐlʔ] ‘flat nosed’ has stress on the first syllable. They both have the incorporated noun root [kɛp] included in the word but they belong to very different grammatical categories with the first as a verb phrase and the second a noun. These differences have not been controlled and consequently they cannot be ruled out as a linguistic difference fortis and geminate stops. The geminates generally occur in different prosodic environments than fortis stops.

8.5 Pressure impulse

As discussed above in § 4.4 and § 6.9, fortis stops are invariably voiceless, with a short, positive termination time. Impressionistically geminates have a higher degree of passive devoicing leading to a longer voice termination time which can be seen in the L_x traces in Figures 8.5, 8.6 and 8.7.

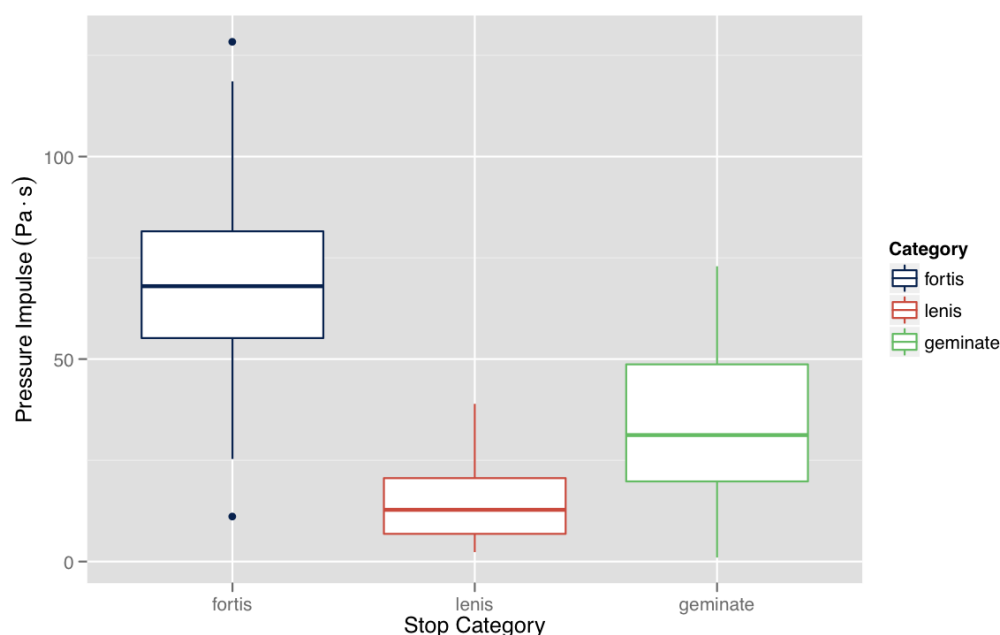


FIGURE 8.8: Pressure impulse showing lenis and fortis stops and geminate clusters.

Bearing in mind the discussion in Chapter 7 and the data presented in Figures 8.8 and 8.9, The only consistent quantifiable phonetic difference between

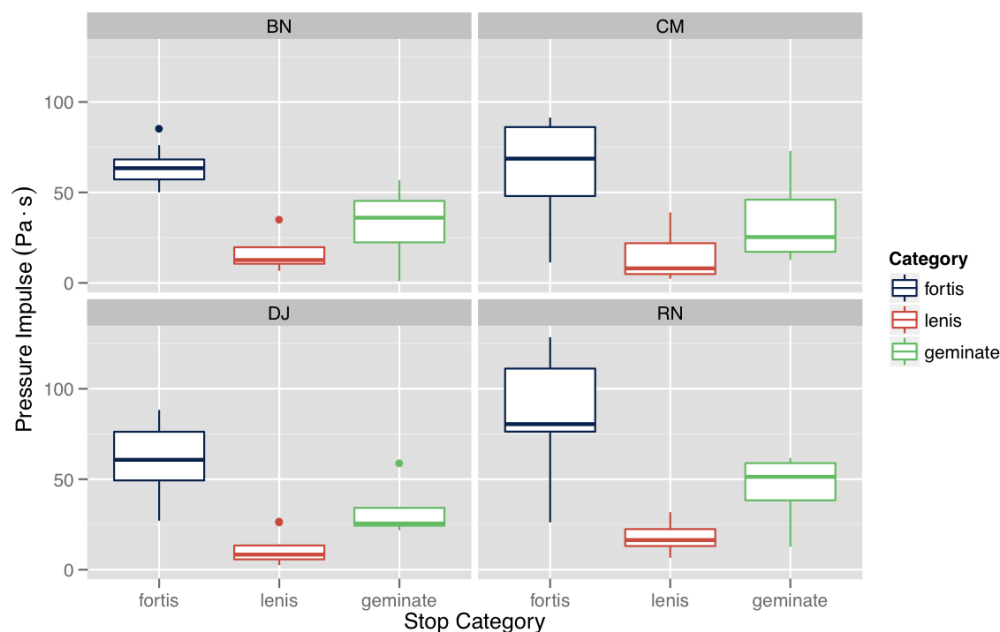


FIGURE 8.9: Pressure impulse showing lenis and fortis stops and geminates separated by speaker.

fortis stops and geminates is the measurement of intra-oral pressure measured as a function of time. This measurement, previously defined as the pressure impulse is the integral of the peak intra-oral pressure curve with the onset and offset of the consonant as limits (see § 5.7.9 for methodological discussion). Differences in pressure impulse between lenis and fortis stops have shown to be significantly different statistically ($\chi^2(8, N=194) = 20.2, p < .001$) with stop category included as a two-tiered fixed factor and speakers and tokens included as random factors. The analysis below includes geminates as another level in the factor analysis. Figure 8.8 below shows that the difference in the pressure impulse is also found between fortis and geminate stops.¹

Figures 8.8 and 8.9 clearly show that there are differences between fortis

¹It should be noted that speakers TD and DN were excluded from this analysis due to insufficient examples of geminate tokens recorded.

stops, lenis stops and geminate stop clusters when measuring the pressure impulse.

When pressure impulse differences are tested with a LMEM ($\chi^2(9, N = 148) = 28, p < .001$) testing a main effect of stop category including three factors (lenis, fortis and geminate) as the fixed factor and speaker, token and recording session included as random factors, each of the factors are shown to be statistically different from one-another. When lenis stops are compared with fortis as they were in the previous chapter there is a difference found between them ($p < .001$). This significant difference is maintained when fortis stops are compared with geminate stops ($p < .001$). This is summarised in Figure 8.8. The difference between lenis stops and geminates is also significant at a 99% confidence level ($p < .01$). *Post hoc* Tukey HSD analysis shows the mean difference between the pressure impulses of fortis stops to be 49 Pa s higher than lenis stops ($p < .01$). Fortis stops have a mean pressure impulse that is 30 Pa s ($p < .01$) higher than geminate clusters (The standard error is ± 5 Pa s for each of these β values). The geminate clusters have a pressure impulse that is 19 Pa s ($p < .01$) higher than lenis stops. This shows that although the geminate clusters have a similar duration to fortis stops, they differ in terms of peak pressure over time (pressure impulse). This suggests that strength of articulation does differ between the lenis and fortis stop categories as reported in the previous chapter and furthermore that geminate clusters form a separate category when the pressure impulse is considered.

8.5.1 Timing of Peak Pressure

Timing has shown to be very important in the phonetic realisation of lenis and fortis stops as both achieve the peak pressure values at similar times. The absolute values of these peaks are different, which indicates that there are different peak pressure targets for lenis and fortis stops. As shown in the figure above (Figure 8.7) the time to reach the peak intra-oral pressure value in geminates

is sometimes delayed when compared with a fortis stop. It is for this reason that geminate clusters have been added to a timing analysis. The main effect of ΔU_o^{MAX} is measured and the difference between fortis and geminates is not shown to be statistically significant (see Figure 8.10) ($p = .82$). There is however, a significant difference between geminates and fortis ($p < .01$) and geminates and lenis stops ($p < .01$) however. This indicates that the geminates form a separate group to fortis stops.

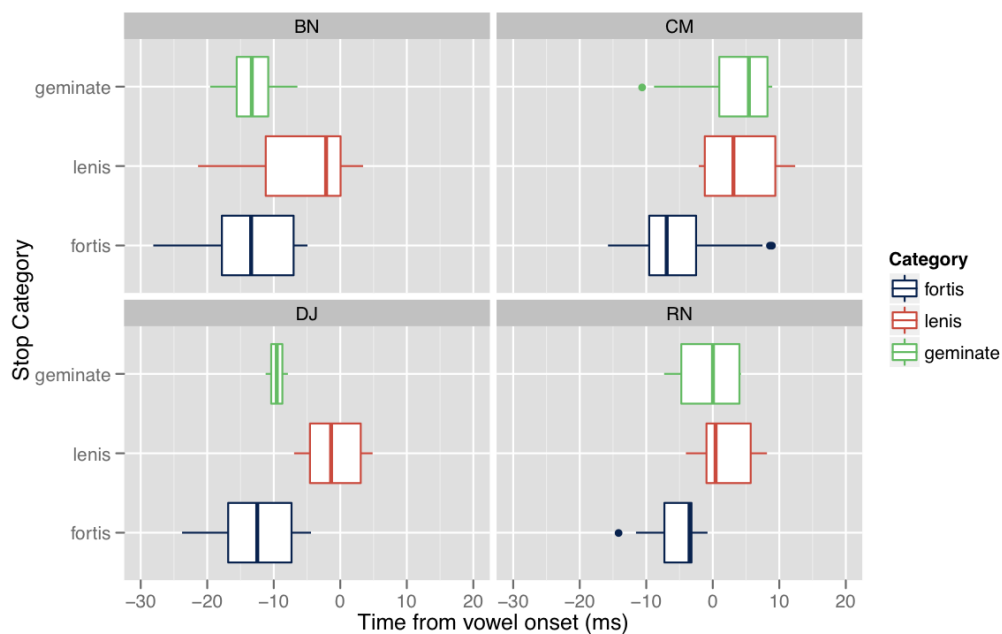


FIGURE 8.10: Timing of Oral flow peak with respect to the vowel onset (ΔU_o^{MAX}) separated by lenis, fortis and geminate.

8.6 Medial stops and voicing patterns

This section investigates voicing patterns in Bini Gun-wok stops using a combination of acoustic, aerodynamic and laryngographic data. The aim is to show whether there is contrastive voicing in the word medial position.

Amongst Australian languages with a single stop series—for example the Pama-Nyungan languages, Warpiri or Arrernte—stops found in the same prosodic

position can be realised phonetically in very different ways (Butcher Pers. Comm, 2012). In languages with a double stop series, the medial fortis stop tends to be phonetically similar to the medial stops of languages that have a single stop series—at least on the surface in terms of voicing patterns and duration. Languages with a single stop series often have medial stops that are voiceless with a long duration, although there is significant variation within these language. There have been no cross-linguistic comparisons beyond Butcher's observations however (Butcher, forthcoming) and the question still remains whether there is some consistency in the observed phonetic realisations. The analysis in this section looks at similarities between the lenis stop and geminates which may be clusters of stops.

8.6.1 Spectral tilt and power spectra results

An acoustic investigation into voice quality in vowels flanking consonants is presented as a comparison to the articulatory data. In this analysis, the three stops categories are separated into three factors, lenis stops, fortis stops and geminate clusters.

As discussed above in § 5.8.1, the $H1^*-H2^*$ measure has been used to indicate differences in glottal tension (DiCanio, 2009). The adjusted $H1^*-H2^*$ has been chosen as the acoustic measure that best correlates with glottal tension. The results show that there is very little difference in the $H1^*-H2^*$ average spectral tilt measurements for each of the consonant environments. There is inter-speaker variation however, and in order to investigate whether there is evidence of a glottal abduction gesture at the consonant onset, the spectral tilt at offset of V_1 and the onset of the consonant is measured. In addition the values for the following vowel (V_2) are also measured to see if there are any glottal differences evident at consonant release. The results have been separated by sex and are shown in Figures 8.11 (males) and 8.12 (females).

These data only show minor differences in the amplitude of $H1^*-H2^*$. To

investigate whether there are any additional measures that can be used to infer the glottal setting at the transition into the consonant, articulatory measurements have been correlated with the acoustic measurements in an experiment involving different speakers. The articulatory measurements include L_x (electroglottograph), and oral airflow (U_o) and pressure (P_o) and these are correlated with various measures of spectral tilt, measured using the acoustic signal. It should be noted that the acoustic signal is degraded as the signal only records the oral component of the speech signal, as discussed above in the methodology (Section 5.7.2, see also § 5.8.1 and § 5.8.3).

For both the males and females there is little difference in the adjusted H1-H2 ($H1^*-H2^*$) at the transition between V_1 and the consonant or homorganic cluster (C, C:, or C_iC_i). The plots (Figures 8.11 and 8.12) show positive amplitudes for adjusted H1-H2, indicating a modal laryngeal setting. These values are not in the range of breathy voice (above 5 dB). The rise that is evident could indicate that there is a glottal abduction gesture at the offset of V_1 . This is strong evidence that supports the hypothesis that there is a change in glottal tension at the V_1C transition. This change is not necessarily an increase, however.

Generally the voice quality, particularly in males, is creaky at the midpoint of the vowel with a low or negative amplitude ($H1^*-H2^* \leq 0$ dB) in the vowel preceding the consonant (V_1) and then returns to a creaky phonation ($H1^*-H2^* \leq 0$ dB) in the vowel following the consonant (V_2). When considered alongside the airflow data measured at the offset of V_1 , the spectral tilt measures show that although there is a low level glottal opening gesture, oral closure is already impeding airflow and consequently there is not the associated peak in oral flow (U_o).

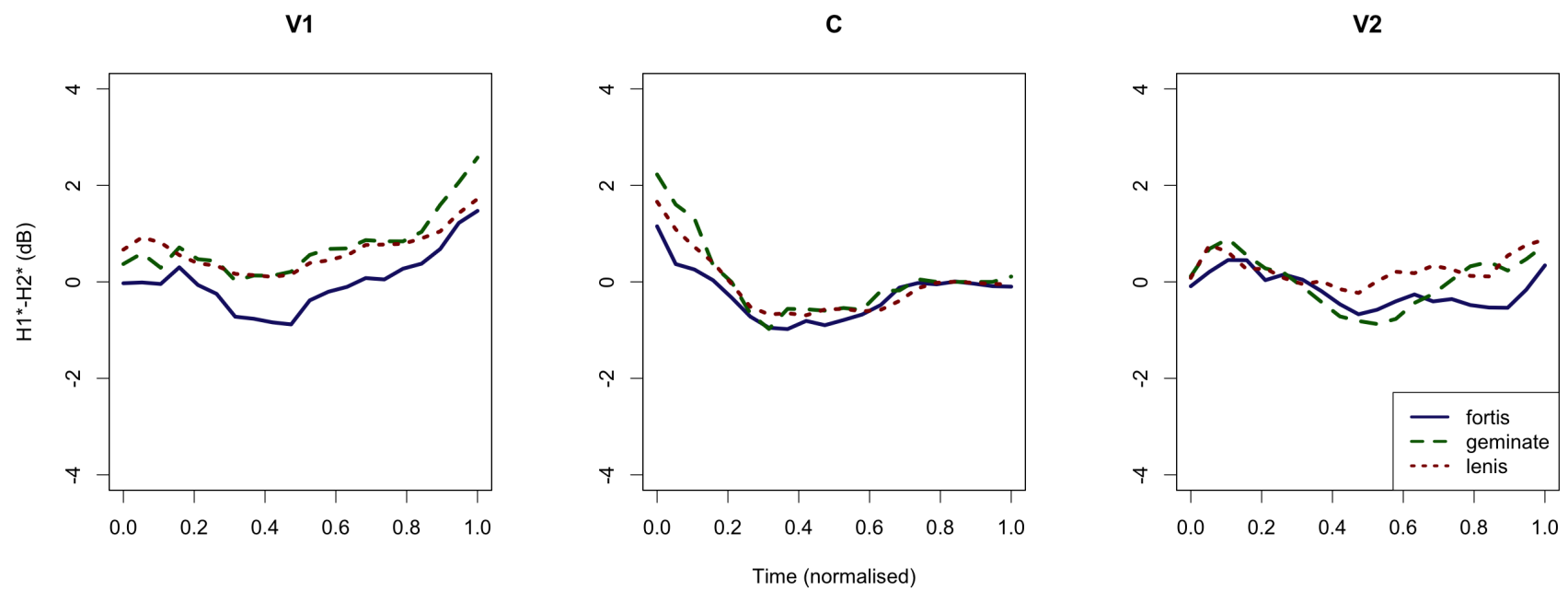


FIGURE 8.11: Male speakers (HK, OK, DK) showing $H1^*-H2^*$ measurements across time in VC:V (fortis), VCCV (geminate) and VCV (lenis) sequences measured from the acoustic signal.

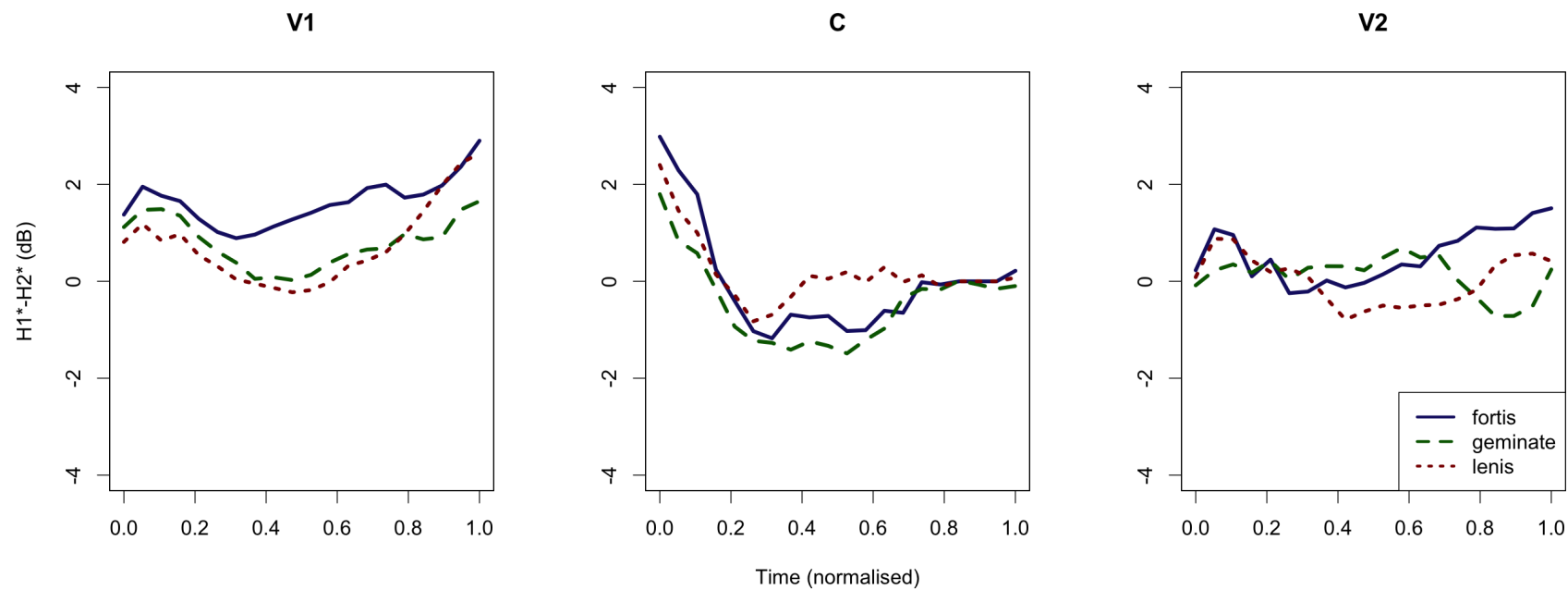


FIGURE 8.12: Female speakers (MM, JM) showing $H1^* - H2^*$ measurements across time in VC:V (fortis), VCCV (geminate) and VCV (lenis) sequences measured from the acoustic signal.

8.7 Discussion

The results presented in this chapter show that duration alone was not sufficient to signal a significant difference between fortis stops (intra-morphemic) from geminated stops (homorganic, inter-morphemic clusters). Heterorganic clusters of two stops have a marginally higher duration than homorganic clusters—a main effect contrasting geminate and clusters of two heterorganic stops with cluster duration is significant including speaker as a random factor. There are insufficient data to test the heterorganic clusters for all combinations of clusters (possibly up to 631 permutations including those that involve nasals, as discussed in § 1.3.2). A systematic analysis of cluster duration in Biniñj Gunwok is a major undertaking that is beyond the scope of this study. The results here however show that the durations of clusters are variable with each combination of place of articulation showing markedly different durations but with no obvious consistency even taking into account the relatively small sample size. This variability is presumably due to the inherent differences in duration shown for each place of articulation, such as the inherently shorter duration for apicals. This variability is thought to be due to the differences in the articulatory gestures.

To summarise the findings of the previous two experiments, lenis stops have shorter durations, lower peak pressures—a low pressure impulse—and no air-flow rise in the preceding vowel. Fortis stops have long durations, high peak pressure—a high pressure impulse—and show a weak airflow rise in the preceding vowel. Geminate clusters have a long duration and a variable peak pressure that patterns between lenis and fortis stops for pressure impulse.

The aim of this chapter is to investigate the variation evident within between fortis stops and geminate clusters. The pressure impulse confirms that there is a difference in pressure, as measured over time, between fortis stops and geminate clusters. The pressure impulse of geminate clusters patterns between

lenis and fortis stops showing that although geminates have a long duration they are often longer than fortis stops (as shown in § 8.2). They also have lower pressures indicating that, they are either articulated with less pulmonic energy or there is incomplete closure at the articulators. The pressure impulse has proven to be the most successful measurement for describing a difference between both lenis and fortis and fortis and geminates.

The pressure impulse measurement does not confirm that there is a difference in force of articulation as defined by Ladefoged and Maddieson (1996). If we consider however that the difference may be due to the difference between a closed system (the fortis stop) and an open system (the lenis stop) this is more in line with Malécot's synaesthetic conceptualisation in the phonetic categorisation of lenis and fortis stop categories (discussed in the previous chapter).

The results of the voicing analysis suggest that there is no increase in glottal tension at the the offset of lenis and fortis stops. At the onset of V_2 there is a brief rise in the $H1^*-H2^*$ which may correlate with a very weak glottal abduction gesture in an effort to prolong voicing as the articulators close. It should be noted that $H1^*-H2^*$ is an acoustic measure and can only give information while there is voicing or higher amplitude information. This is not as useful for voiceless stops by their very nature. The electroglottographic data is correlated (inversely) with the results of $H1^*-H2^*$ and they agree in many respects. More controlled data are needed to generalise however.

Jaeger (1983, p. 188) cites Catford (1977, p. 203) who says that "...the terms tense/lax, strong/weak, fortis/lenis and so on, should never be loosely and carelessly used without precise phonetic specification." It is clear that there is a measurable difference between the two stop types, sufficient to justify categorising them as fortis and lenis stops but is there a measurable difference between three categories? Results show that although there is no significant durational difference between fortis and geminates there are clear pressure differences. The pulmonic airflow is similar for both for all three stop categories

yet there is a proven articulatory difference that involves tight timing and gestural co-ordination between the supra-laryngeal articulators and the larynx.

In conclusion, although the geminates have a long duration they do not consistently meet the tight closure criterion necessary for a pressure rise and as a consequence the sensory feedback is absent. The prosodic differences between fortis stops and geminate can not be ruled out as the source of the phonetic differences between them, however.

Chapter 9

Nasal coarticulation: an aerodynamic analysis

Australian languages generally have nasal consonants that match for place of articulation with a corresponding stop series. And sonorants in general are very common lexically. Sonorants comprise 70% of the typical Australian phoneme inventory and with the remaining 30% obstruents. Cross-linguistically this pattern is unusual with phoneme inventories of many languages consisting mainly of obstruents (Butcher, 1999, 2006a, forthcoming). In Australian languages, nasals can occur in both syllable onset and coda position at all places of articulation (Hamilton, 1996). Bininj Gun-wok has numerous consonant clusters that can legally involve nasals due to its highly agglutinative morphology. This feature singles it out as a highly suitable Australian language for investigating the effects of co-articulation and assimilation (see § 1.3.2 and Evans, 2003).

This chapter investigates the levels and direction of influence of nasal coarticulation in Bininj Gun-wok, building on work by Butcher. Evidence from a number of Australian languages has shown a tendency to delay the opening of the velar port when a nasal follows a non-nasal segment (Butcher, 1999, 2006a; Butcher & Loakes, 2008). At the extreme end is phonological pre-stopping, as found in Eastern/Central Arrernte, but there is also evidence that a delay

to velum lowering before nasals is widespread amongst Australian languages, which has been demonstrated in languages neighbouring but not related to Bininj Gun-wok such as Gupapuyngu and Burarra (Butcher, 1999, 2006a). This tendency to delay the onset of nasalisation may be an effort to preserve the perceptual saliency of place of articulation cues as discussed above in relation to the place of articulation imperative (§ 4.3).

9.1 Aims and research questions

The research questions and hypotheses, outlined in § 4.5 on page 99, introduce a number of observations regarding the phonetic aspects of nasalisation in Bininj Gun-wok and other Australian languages. The first question is whether nasalisation is predominantly anticipatory or perseverative in Bininj Gun-wok. Anticipatory nasalisation occurs when the velum is lowered allowing air into nasal cavity prior to the onset of the oral closure in a nasal segment. This is sometimes referred to as right-to-left assimilation (Kawasaki, 1986). Perseverative, carry-over or left-to-right nasalisation occurs when, in a nasal articulation, the velum remains lowered or open after the release of closure in the oral cavity. Anticipatory nasalisation is thought to be under active control whereas carry-over nasalisation is said to be due to bio-mechanical inertia and therefore not under active control (Recasens, 1989). It has been shown in a number of Australian languages including Warlpiri (Fletcher et al., 2009) and Iwaidja (Fletcher et al., 2011) that although there is temporal coproduction there are only limited spatial modifications in apical nasals (Fletcher et al., 2010). Butcher (2006a) cites the example /'jinka/ 'laughter' from Warlpiri and notes that it is phonetically realised as [ʲjɪnkə] but never as *[ʲjɪŋkə] even in connected speech. Heterorganic clusters of nasals followed by a stop have an unusual stability in terms of resisting place assimilation. Butcher (2006a) gives an example of an EPG recording showing a /n/ followed by /k/ sequence in the

place name *Ankabadbirri* by a Bininj Gun-wok speaker (CL, Kune dialect).

In Bininj Gun-wok it has previously been shown by Fletcher et al. (2010) that the duration of nasals is longer in NC clusters. This agrees with studies on Warlpiri and Arrernte which have shown that single nasals are shorter than nasals in clusters (Butcher, forthcoming). Additionally, many homorganic nasal clusters have a shorter duration than heterorganic clusters—particularly /ŋk/ clusters (Fletcher et al., 2010, p. 80). In addition, single palatal (alveo-palateal) nasals (/ɲ/) have significantly longer transitions from vowels to nasals when measuring formant information at the vowel target to the onset of the consonant.

Restating the hypotheses, there are two central questions (Q) and a number of related hypotheses (H) investigated in this chapter:

Experiment 3. H1. In a $V_1N_1V_2$ sequence, the peak nasal-flow (U_n^{MAX}) is delayed with respect to oral closure.

H2. A $V_1C_1N_1V_2$ shows a different patterning to a $V_1N_1C_1V_2$ sequence with regard to the realisation of the nasal.

Q1. What is the extent and directionality of a nasal's influence on the surrounding segments in terms of nasalisation?

Q2. Do nasals have a longer duration in nasal + consonant (NC) clusters?

Q3. What are the aerodynamic constraints that control rapid velar lowering?

Some additional questions will be considered in the course of the experiments. A byproduct of a delay in velum lowering is that there is some epenthetic pre-stopping for many speakers of Australian languages (Butcher, 1999; Butcher & Loakes, 2008). When the timing of velar opening is delayed until well after oral closure there is a period of both oral and nasal closure that can be termed

prestopping (Butcher & Loakes, 2008; Maddieson & Ladefoged, 1993). Prestopping of nasals and laterals (Hercus, 1972; Loakes et al., 2008) is widespread amongst Australian languages and is analysed as phonological in a small number of these languages (see § 4.3). Fletcher et al. (2010, p. 80) have shown that there are very few examples of prestopping in Kunwinjku when analysing nasals acoustically and the anterior places are more likely to prestop. Prestopping has not shown to be phonological in Bininj Gun-wok, and in addition it has not been described as such in previous linguistic analyses. (Carroll, 1976; Evans, 2003).

9.2 An acoustic analysis of nasals

9.2.1 Duration results

The following duration measurements are reported in Tables 9.1 to 9.6 on pages 279–285 below:

1. The duration of singleton nasals in a VNV sequence.
2. The total duration of a nasal followed by a stop in a medial VNCV sequence (both homorganic and heterorganic).
 - The duration of the nasal in a VNCV sequence.
 - The duration of the stop in a VNCV sequence.
3. The total duration of a stop followed by a nasal in a medial VCNV sequence (both homorganic and heterorganic).
 - The duration of the nasal in a VCNV sequence.
 - The duration of the stop in a VCNV sequence.

Table 9.1 on the facing page shows the mean duration for medial nasals between two vowels. The number of tokens (n) for three places (bilabial, velar

and apico-alveolar) is between 66 and 82 tokens and represent all of the words in the nasal word list. This excludes the words in the carrier phrase although these too have medial single nasals. The durations for each token are quite similar regardless of place of articulation except in the post alveolar (retroflex) nasals that shows durations of between 45 ms to 55 ms. The alveolar and bilabial nasals have the longest duration with mean durations of 95 ms and 112 ms respectively. A linear mixed effects model (LMEM) testing a main effect of nasal duration with place of articulation as a fixed effect and speaker as a random effect ($\chi^2(7, N=320) = 2.15, p = .71$) does not show a significant difference between the means any of the nasal places of articulation using a *post hoc* Tukey HSD test.

TABLE 9.1: Duration of singleton nasals (VNV) (ms).

	Peripheral		Coronal		
	<i>bilabial</i>	<i>velar</i>	<i>apical</i>		<i>laminal</i>
			<i>alveolar</i>	<i>retroflex</i>	<i>palatal</i>
singleton	m	ŋ	n	ɳ	ɲ
$\bar{x}$	112	84	95	50	91
<i>s.d.</i>	60	28	54	8.82	36
<i>n</i>	82	70	66	10	24

The duration measurements of the individual words are reported in Tables 9.2 and 9.3. These tables show that the nasal durations are similar for both individual words and when measured across place of articulation. It should be noted that there is only one word in the corpus with a medial singleton apico-postalveolar (retroflex) place of articulation, *karnubirr*, ‘fresh water mussel’. This word however, has a retroflex nasal measured in pre-tonic stress position in a three syllable word and it is problematic to compare this word to the other nasals in the corpus which are mainly in post-tonic position. The mean dura-

tion of the retroflex nasals is lower (50 ms) (Table 9.1 on the previous page) with less variation shown by the smaller standard deviation (s.d.). The large range in the standard deviations across all places of articulation may be due to the different speech rates amongst the speakers and for different elicitation sessions. However, the LMEM includes token identity as a random factor.

TABLE 9.2: *Duration (ms) of medial singleton nasals in words within a carrier phrase (a).*

Word	kamak	kumoken	bininj	kunak
<i>n</i>	22	14	30	19
<i>mean</i>	100	87	74	71
<i>s.d.</i>	24	16	15	11

TABLE 9.3: *Duration (ms) of medial singleton nasals in words within a carrier phrase (b).*

Word	kinga	kangokme	ngalmangiyi	kanjok	karnubirr
<i>n</i>	23	11	37	21	18
<i>mean</i>	94	76	75	80	59
<i>s.d.</i>	16	20	18	15	20

Table 9.4 on the facing page shows the mean duration in medial intervocalic clusters of a nasal (N_1) followed by a stop (C_1). Stops are denoted by C, standing for consonant, despite nasals also being consonantal. Nasals are denoted by N in this experiment. Table 9.4 reports durations for both homorganic and heterorganic clusters and these are shown separately. In each of the homorganic and heterorganic clusters the oral stop following nasal is invariably voiced—see above. The duration of the nasal (N_1) is longer in duration than the oral stop (C_1) by almost a factor of two.

TABLE 9.4: Duration of nasal (N_1) + stop (C_1) clusters and the individual segments in CVNCV sequences (ms), mean ($\bar{x}$), standard deviation ($s.d.$) and number (n).

		Peripheral				Coronal					
						apical			laminal		
		bilabial		velar		alveolar		retroflex	palatal		
homorganic		$m \rightarrow b$		$\eta \rightarrow g$		$n \rightarrow d$		$\eta \rightarrow \text{ɖ}$	$\text{ɲ} \rightarrow c$		
cluster duration	$\bar{x}$	162		134		146		122	166		
	$s.d.$	47		34		62		24	61		
	n	26		27		74		39	20		
		m	b	η	k	n	d	η	ɖ	ɲ	ɟ
segment duration	$\bar{x}$	109	55	82	51	103	49	84	37	97	67
	$s.d.$	34	40	26	22	60	40	22	14	36	36
heterorganic		$m \rightarrow C$		$\eta \rightarrow C$		$n \rightarrow C$		$\eta \rightarrow C$	$\text{ɲ} \rightarrow C$		
cluster duration	$\bar{x}$	162		202		167		—	—		
	$s.d.$	34		63		42		—	—		
	n	50		43		130		0	0		
		m	C	η	C	n	C	η	C	ɲ	C
segment duration	$\bar{x}$	106	55	126	76	104	70.2	—	—	—	—
	$s.d.$	29	21	34	56	39	52	—	—	—	—

TABLE 9.5: Duration of stop (C_1) + nasal (N_1) clusters and segments (mean, standard deviation and number) in CVCNV sequences (ms).

		Peripheral				Coronal					
						apical				laminal	
		bilabial		velar		alveolar		retroflex		palatal	
		$p \rightarrow m$		$k \rightarrow \eta$		$t \rightarrow n$		$\text{ɖ} \rightarrow \text{ɳ}$		$c \rightarrow \text{ɲ}$	
homorganic	cluster duration	$\bar{x}$	238	-	-	172	-	255	-	-	-
		<i>s.d.</i>	44	-	-	50	-	-	-	-	-
		<i>n</i>	29	0	0	9	1	0	-	-	-
		p	m	k	η	t	n	ɖ	ɳ	ɟ	ɲ
segment duration	$\bar{x}$	180	57	-	-	129	43	195	60	-	-
	<i>s.d.</i>	64	50	-	-	39	19	-	-	-	-
		$C \rightarrow m$		$C \rightarrow \eta$		$C \rightarrow n$		$C \rightarrow \text{ɳ}$		$C \rightarrow \text{ɲ}$	
heterorganic	cluster duration	$\bar{x}$	217	176	-	240	-	-	-	-	-
		<i>s.d.</i>	50	41	-	48	-	-	-	-	-
		<i>n</i>	129	33	-	39	0	0	-	-	-
		C	m	C	η	C	n	C	ɳ	C	ɲ
segment duration	$\bar{x}$	150	71	102	73	154	86	-	-	-	-
	<i>s.d.</i>	58	29	40	26	58	36	-	-	-	-

The nasal segment in a cluster of a stop followed by a nasal has a shorter duration than singleton nasals, a result that is supported in previous studies of Bininj Gun-wok (Fletcher et al., 2010). The stop.nasal clusters have a noticeably longer duration than the nasal.stop clusters, which may be due to more effort involved in their articulation.

In Table 9.5 the stops (C_1) shown are invariably voiceless and longer than the following nasal (N_1). This duration difference is observed in both homorganic and heterorganic clusters. The duration for a nasal (N_1) that is part of a cluster is lower than the mean duration for a singleton nasal at the same place of articulation (shown in Table 9.1 on page 279). The entire cluster duration in stop + nasal clusters is greater than the cluster duration for the nasal + stop sequences. When measuring the nasals segments across all of the segmental environments the nasals have very consistent durations including the nasal + stop (table 9.4 on page 281) and stop + nasal clusters (Table 9.5 on the preceding page).

In summary, the durational results of cluster duration, separated by speaker, are shown in Figure 9.1. The VCNV environment has the longest overall duration for all speakers. The VNCV environment is shorter than VCNV overall for all speakers and the mean durations for single nasals in an VNV sequence are all under 100 ms for all speakers.

These observations are confirmed statistically. The results of a LMEM ($\chi^2(6, N=474) = 151, p < .001$) show that a main effect of cluster duration, when the sequence structure (VNV, VCNV or VNCV) is included as a fixed factor and speaker and token are included as random factors, are statistically different from one another (all $p < .001$). In a *post hoc* analysis, the duration of VCNV also differed significantly from VNCV ($p < .001$).

When isolating the nasal duration from each of these sequences however, the LMEM does not allow the rejection of the null hypothesis at the 1% level, ($\chi^2(6, N=474) = 6.63, p = .04$). This suggests that the nasals in each of these

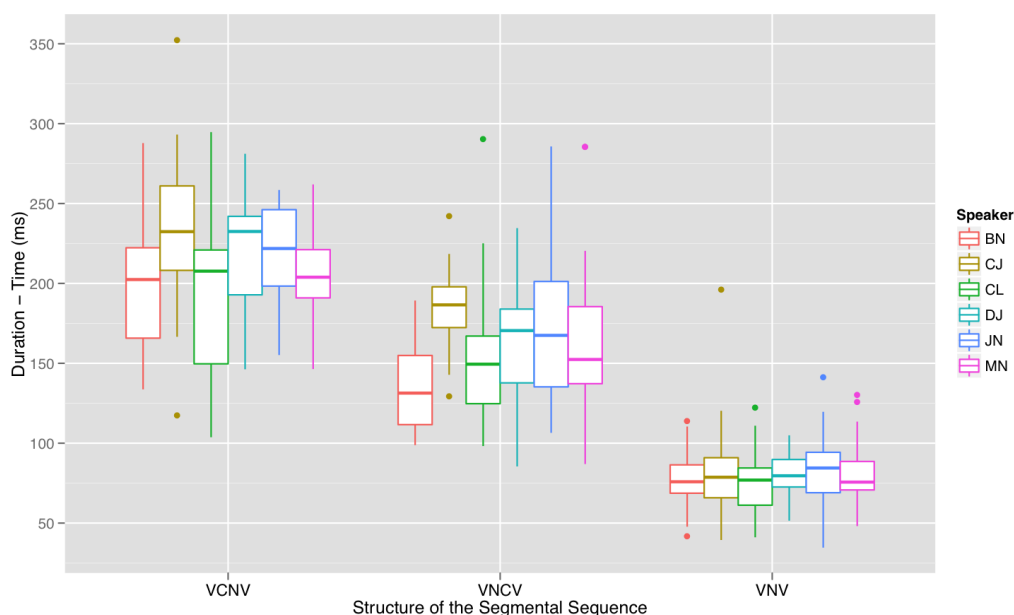


FIGURE 9.1: Summary of duration measurements in single nasals (N) and nasal clusters (CN) and (NC).

sequences have a similar duration. These are however based on purely acoustic results and consequently it is very difficult to accurately segment these data into the constituent segments. The transition between nasal and stop is a gradient phenomenon without clear boundaries particularly in the environment of voiceless stops. For these reason the results need further scrutiny with the addition of aerodynamic data. It should be noted that, based on this analysis, the duration of single intervocalic nasals is not dependent on place of articulation. Retroflex (apico-postalveolar) nasals [ɳ], however appear to have a shorter duration although this is not confirmed statistically (see Table 9.4). This lack of statistical power may be due to the relatively small sample size at this place of articulation, so further measurements are need for this to be conclusive.

9.2.2 Prestopped nasals

Table 9.6 shows the durational results for prestopped nasals before single nasals. The prestopped nasals are not phonemically contrastive as they are in free variation with non-prestopeed nasals. Consequently these are analysed as a single segment rather than a cluster. Referring back to Table 9.5, the duration of the stop in an homorganic C_iN_i cluster shows to be far higher than that of the prestopped nasals. For example, 180 ms for [p] in an homorganic bilabial cluster but only 27 ms in a prestopped nasal. The prestopped portion is invariably voiced whereas the stop in a CN cluster is always voiceless. It is for this reason that prestopped nasals are analysed as an allophone of a plain singleton nasal in Biniŋ Gun-wok rather than some form of reduced cluster. The prestopping is much more prevalent in bilabials ($n = 25$) and apicals ($n = 33$) than at the other places of articulation but this may be more to do with the number of tokens at these places of articulation rather than a true representation of the population.

TABLE 9.6: *The duration of prestopped nasals (ms).*

	Peripheral		Coronal		
	bilabial	velar	apical		laminal
			alveolar	retroflex	palatal
prestop + nasal	^b m	^g ŋ	^d n	^d ɳ	^j ɲ
<i>n</i>	25	4	33	5	4
$\bar{x}$	108	127	98	95	125
<i>s.d.</i>	24	20	29	13	36
prestop	b	g	d	ɖ	j
$\bar{x}$	27	20	26	15	24
<i>s.d.</i>	15	10	29	4	14

The duration results show that in a nasal cluster—either stop + nasal or nasal + stop—the initial member of the cluster consistently shows a longer duration. This may suggest some sort of syllable final fortition as these clusters are at a syllable boundary. This is consistent with the duration measurements in stops presented in Chapter 5.

These durational results do not give any information about directionality of nasalisation however. In order to obtain an adequate phonetic description of this delay in velum opening the aerodynamic data will now be examined in depth.

9.3 An aerodynamic analysis of nasals

9.3.1 Average flow rates

In general, the aerodynamic results from all speakers show that nasal air flow is much lower in magnitude than oral airflow. These results are as expected due to the smaller aperture present in the nasal cavity when compared with that of the oral cavity (Baken & Orlikoff, 2000). When comparing across speakers it is necessary to average the measured airflow in an effort to normalise the effects of inter-speaker flow-rate differences. The patterns of peak flow timing is markedly different for individual words (see § 5.9.3 on page 166). These initial results displayed in the following tables 9.7 to 9.11 on pages 288–291 show the mean flow rates for VNV sequences, separated by speaker.

In the sequence of V_1NV_2 without an initial nasal there is very little nasal airflow observable in the first vowel (V_1) of the sequence (which is shown in table 9.7 on page 288). The nasal flow is greater for V_2 but there is a lesser flow rate than that of the nasal preceding it. The flow rates in V_1 are below the error threshold set of $\pm 5 \text{ cm}^3 \text{ s}^{-1}$, which indicates that they are very close to no observable nasal flow. The oral flow results show the flow rate is less in V_2 when compared to V_1 in the same V_1NV_2 sequences, reflecting the higher nasal flow shown in the corresponding segment. Each table shows the mean ($\bar{x}$), standard deviation (*s.d.*) and number of token (*n*). The tables are all separated by place of articulation with the peripheral consonants grouped together. To ensure that speaker specificity is not affecting the results, each speaker is measured and analysed separately in keeping with the previous experiments. For all

speakers there is positive nasal airflow in the second vowel and almost no nasal airflow on the first vowel (shown in Table 9.7). This points to greater carry-over nasalisation rather than anticipatory nasalisation, supporting the first hypothesis (H1). The average oral flow is reported in table 9.10 on page 290, separated by speaker.

TABLE 9.7: Mean nasal airflow ($\bar{U}_n$) of segments in VNV sequences (measured in $\text{cm}^3 \text{s}^{-1}$).

		Peripheral						Coronal							
								<i>apical</i>				<i>laminal</i>			
								<i>alveolar</i>		<i>retroflex</i>		<i>palatal</i>			
		<i>bilabial</i>			<i>velar</i>										
VNV	V ₁	m	V ₂	V ₁	ŋ	V ₂	V ₁	n	V ₂	V ₁	ɳ	V ₂	V ₁	ɲ	V ₂
<i>U_n</i>	3	39	31	7	52	18	5	35	26	3	27	24	4	33	28
<i>s.d</i>	3	25	22	6	37	13	4	22	15	4	21	22	3	28	23
<i>n</i>		22			17			13			10			9	

TABLE 9.8: Mean oral airflow ($\bar{U}_o$) of segments in VNV sequences (measured in $\text{cm}^3 \text{s}^{-1}$).

		Peripheral						Coronal							
								<i>apical</i>				<i>laminal</i>			
								<i>alveolar</i>		<i>retroflex</i>		<i>palatal</i>			
		<i>bilabial</i>			<i>velar</i>										
VNV	V_1	m	V_2	V_1	ŋ	V_2	V_1	n	V_2	V_1	ɳ	V_2	V_1	ɲ	V_2
$\overline{U}_o$	149	66	125	178	43	116	139	61	79	110	103	98	181	92	100
<i>s.d.</i>	56	37	62	95	26	70	78	23	37	88	102	85	91	60	67
<i>n</i>		19			17			15			10			9	

TABLE 9.9: Mean nasal airflow ($\bar{U}_n$) of segments in VNV sequences (measured in $\text{cm}^3 \text{s}^{-1}$) separated by speaker.

SPEAKER		Peripheral						Coronal								
								apical						laminal		
		bilabial			velar			alveolar			retroflex			palatal		
		V_1	m	V_2	V_1	ŋ	V_2	V_1	n	V_2	V_1	ɳ	V_2	V_1	j	V_2
BN	$\bar{U}_n$	3	27	27	7	42	14	8	23	21	3	16	13	4	26	20
	<i>s.d.</i>	1	5	8	2	10	5	6	6	4	3	7	4	3	9	6
	<i>n</i>		6			3			4			3			3	
CL	$\bar{U}_n$	2	43	31	5	85	23	1	40	35	2	23	29	0	31	24
	<i>s.d.</i>	3	9	8	7	16	10	0	5	11	1	3	1	—	—	—
	<i>n</i>		6			3			2			2			1	
DJ	$\bar{U}_n$	3	17	16	1	20	9	1	11	7	—	—	—	—	—	—
	<i>s.d.</i>	2	7	17	0	7	5	—	—	—	—	—	—	—	—	—
	<i>n</i>		4			2			1			0			0	
JN	$\bar{U}_n$	2	42	23	12	61	24	5	52	37	2	29	18	2	24	24
	<i>s.d.</i>	1	14	8	9	44	8	3	23	9	1	8	7	1	2	8
	<i>n</i>		3			4			3			2			3	
MN	$\bar{U}_n$	8	81	67	7	57	22	3	37	23	6	40	36	8	58	47
	<i>s.d.</i>	2	42	43	9	61	27	3	34	26	8	37	40	3	66	56
	<i>n</i>		3			3			3			3			2	

TABLE 9.10: Mean oral airflow ($\bar{U}_o$) of segments in VNV sequences (measured in $\text{cm}^3 \text{s}^{-1}$) separated by speaker.

SPEAKER		Peripheral						Coronal								
		bilabial			velar			apical					laminal			
								alveolar			retroflex		palatal			
		V_1	m	V_2	V_1	ŋ	V_2	V_1	n	V_2	V_1	ɳ	V_2	V_1	j	V_2
BN	$\bar{U}_o$	134	77	104	238	33	141	95	64	97	75	92	83	199	95	89
	<i>s.d.</i>	61	52	76	146	26	96	19	23	39	25	76	60	103	56	53
	<i>n</i>		4			3			4			3			3	
CL	$\bar{U}_o$	181	90	183	243	56	201	278	85	79	262	273	243	270	184	251
	<i>s.d.</i>	56	32	50	22	28	46	7	20	18	52	50	33	—	—	—
	<i>n</i>		6			3			2			2			1	
DJ	$\bar{U}_o$	106	37	69	122	29	75	112	35	49	—	—	—	—	—	—
	<i>s.d.</i>	47	24	44	117	29	71	—	—	—	—	—	—	—	—	—
	<i>n</i>		3			2			1			0			0	
JN	$\bar{U}_o$	163	60	120	109	32	67	152	57	68	46	35	32	154	85	67
	<i>s.d.</i>	68	24	28	71	25	38	63	18	49	38	28	22	117	73	42
	<i>n</i>		3			4			3			2			3	
MN	$\bar{U}_o$	135	39	99	234	55	137	172	68	98	85	45	62	153	52	89
	<i>s.d.</i>	38	22	20	19	31	21	24	22	32	42	30	24	72	17	20
	<i>n</i>		3			3			3			3			2	

TABLE 9.11: Percentage of Nasal Flow as a proportion of total flow ($U_o + U_n$) of segments in VNV sequences (%).

SPEAKER		Peripheral						Coronal								
								apical						laminal		
		bilabial			velar			alveolar			retroflex			palatal		
		V_1	m	V_2	V_1	ŋ	V_2	V_1	n	V_2	V_1	ɳ	V_2	V_1	ɲ	V_2
BN	PNF(%)	3	36	35	5	64	12	7	28	19	5	21	18	3	27	23
CL	PNF(%)	2	34	15	2	61	11	0	32	30	1	8	11	0	15	9
DJ	PNF(%)	3	35	20	2	49	18	1	23	12	—	—	—	—	—	—
JN	PNF(%)	1	42	17	16	62	31	3	48	41	7	49	40	4	35	32
MN	PNF(%)	6	66	38	3	45	13	2	33	17	9	43	31	5	44	30

To summarise the tabular data presented on the previous pages, only VNV sequences are initially examined. Table 9.7 on page 288 and the Table 9.8 on page 288 show the averaged nasal and oral flow in a VNV sequence respectively. Table 9.9 on page 289 and Table 9.10 on page 290 repeat these measurements, but this time they are separated by speaker. Table 9.11 on the previous page combines the oral and nasal flow and shows nasal flow as a proportion of the total flow (U_{total}).

Examining the results in Table 9.10 in greater detail shows some notable results. For the majority of speakers, a higher nasal airflow results in a lower mean oral airflow. This is due to the redirection of the air into the nasal cavity directing air away from the oral cavity. As discussed previously, the oral and nasal flow rates are averaged across the entire segment. The mean oral flow remains positive during the nasal which may indicate partial or incomplete oral closure similar to the articulation in lenis oral stops (see § 6.9).

The proportional nasal flow shows that in the vowel preceding a nasal (V_1) there is very little positive flow (shown in Tables 9.9 and 9.11). The only speaker to register an nasal airflow that does not conform to this pattern for V_1 is speaker JN, who at the velar place of articulation has a nasal flow rate at 16% of the total flow rate in the initial vowel. The remainder of the speakers show values that are at, or below 9% of the total flow rate. The majority of average proportional nasal flow rates in the vowel following the nasal (V_2) however, are above 20% of the total airflow rate. It is clear from these flow results that although there are very low levels of anticipatory nasal flow there are greater levels of carry-over nasalisation in vowels following nasals. These are however average values and it is difficult to generalise from them alone the precise timing of the velum opening gesture. Nasal flow as a function of time must be calculated and plotted and the results of this analysis are summarised in the following section.

9.3.2 Nasalisation in VNV sequences

The plots in Figures 9.2 to 9.5 on pages 294–296 shows the average oral airflow ($\overline{U}_o$) and average nasal airflow ($\overline{U}_n$) (both shown on the y-axis), for single intervocalic nasals plotted with the surrounding vowel environment. Normalised airflow ($\text{cm}^3 \text{s}^{-1}$) is plotted against normalised time (shown on the x-axis).

In each plot the vowel and nasal are first normalised for time and then the nasal airflow average for six speakers is calculated for each segment using *Emu/R* (Harrington et al., 2012). The resulting average for each place of articulation is plotted in a separate figure.

The normalised segments are each time-aligned based on the hand-labelled transition of vowel (V_1) to nasal (N_1), labelled using the acoustic signal. This normalising procedure is done using commands within *Emu/R* as part of The Emu Speech Database (Harrington et al., 2012). This averaging does little to affect the moment of the initial rise in nasalisation although it does make the magnitude information less informative as there is a very wide cross-speaker variation in flow rates as shown above.

In each of the figures the oral airflow shows a negative value in the nasal closure. The magnitude of this is largely associated with the normalisation technique but it should be noted that there is some ingressive airflow as the nasal reaches a flow peak. The figures, better illustrate relative timing of rises and peaks of nasal airflow to the vowel (V_1), nasal (N) transition however.

At the bilabial place of articulation (shown in Figure 9.2), a rise in the mean nasal airflow ($\overline{U}_n$) is precisely coincident or even slightly delayed with respect to the closure in the nasal (this point is marked at 0.33 on the Normalised Time axis (x-axis)). In the following vowel (V_2) there is positive nasal flow throughout the entire segment. The average peak nasal flow rate occurs after 50% of the oral closure, well within the nasal segment. These plots are consistent with the averaged flow values shown above in Table 9.9.

Intervocalic apical nasals (/n/) (Figure 9.3) also show a delay in the average

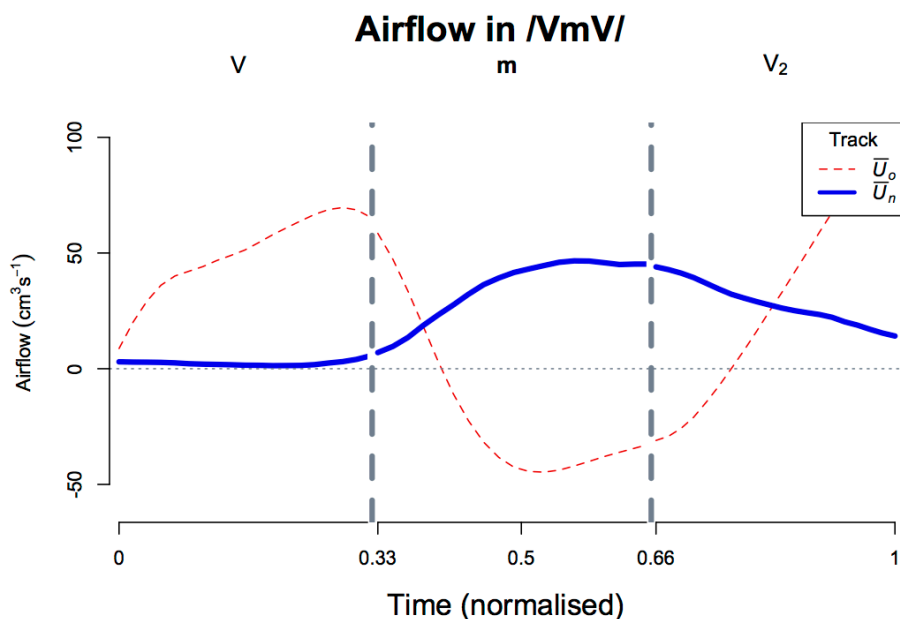


FIGURE 9.2: Average airflow of bilabial nasals in a time normalised sequence of *V* followed by *N* in a *VNV* sequence.

nasal airflow ($\overline{U}_n$). This is also shown to be after the oral occlusion in the nasal.

Intervocalic palatal nasals (/ɲ/) (Figure 9.4) have a similar patterning. In these sequences the average peak nasal flow is found in the following vowel (V_2). The oral occlusion in palatals uses the tongue blade to create a wide closure behind the alveolar ridge (see § 4.4.2).

Intervocalic apico-postalveolar (retroflex) nasals (/ɳ/) (Figure 9.5) show slight anticipation. This may be due to the relatively short duration at this place of articulation.

All places of articulation show almost no anticipatory nasalisation in the preceding vowel when the average nasal airflow is measured. There are marginally higher levels of nasal airflow observed in the intervocalic retroflexes. These higher flow levels are likely due to the time normalisation method used in these plots.

The duration of the retroflex nasal is relatively short compared with nasals

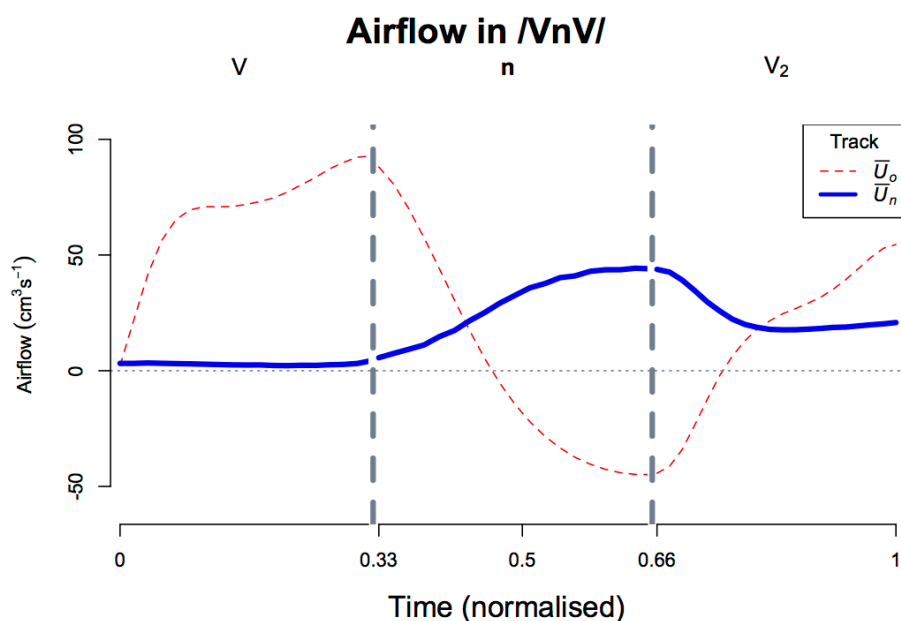


FIGURE 9.3: Average airflow of apical nasal in a time normalised sequence of a VN sequence.

at other places of articulation, although this is not confirmed statistically. Referring back to the duration measurements reported in Table 9.1 on page 279 retroflex intervocalic nasals ($/\eta/$) show the shortest mean duration (51 ms), compared with a mean duration of 84 ms for the intervocalic velar nasals ($/\eta/$).

There is greater nasal airflow preceding the closure at the velar place of articulation (shown in Figure 9.6). This suggests that the velum opens early with respect to oral closure when compared with the other places of articulation. The absolute duration is however exceptionally short. This is possibly due to interference from the tongue root in the very posterior articulation of velars in Bininj Gun-wok (see § 1.3). Velars are generally articulated very far back in the oral cavity for most speakers and can be described as having an uvular allophone, particularly in close-back or mid-close back vowel environments. It should be noted that these are very short anticipatory durations however. The oral airflow in the preceding vowel has a number of distinct patterns and this

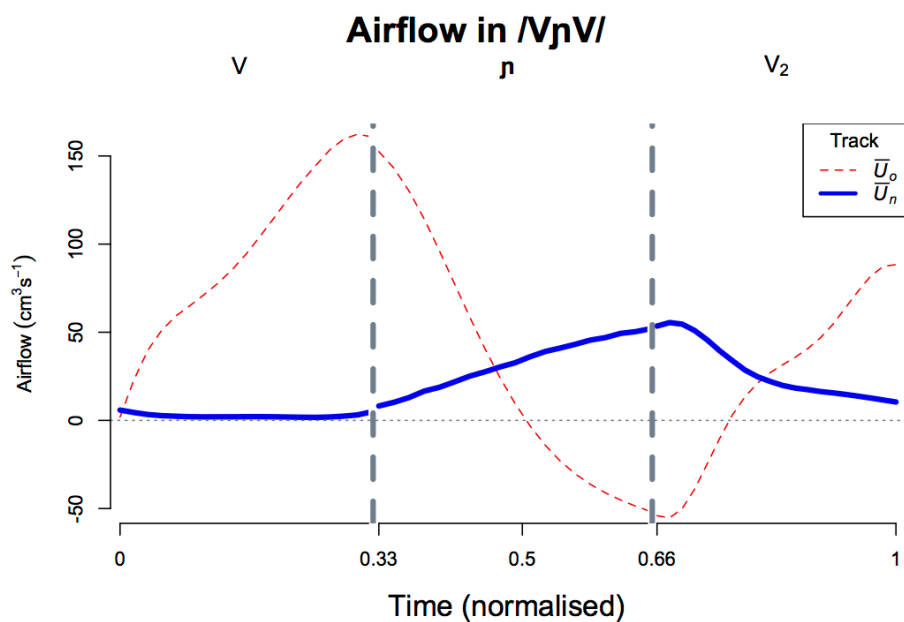


FIGURE 9.4: Average airflow of palatal nasal in a time normalised sequence of a VNV sequence.

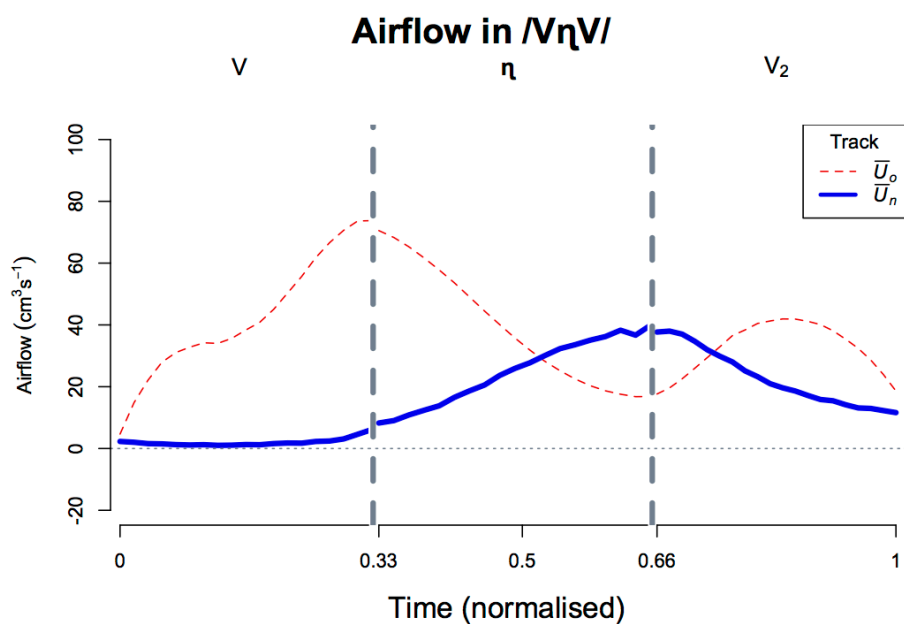


FIGURE 9.5: Average airflow of retroflex nasal in a time normalised sequence of a VNV sequence.

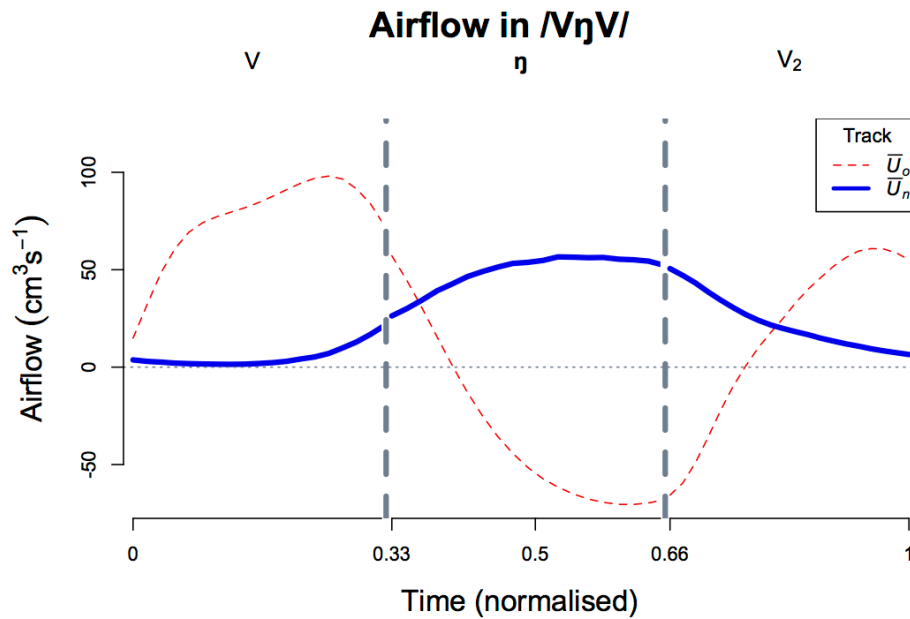


FIGURE 9.6: Average airflow of velar nasals in a time normalised sequence of a VNV sequence.

will be explored in greater detail below.

9.3.3 Normalised flow in NVN sequences

In nasal initial words there is significant amounts of nasal influence on the following vowel and the airflow remains fairly steady until an oral closure. Figure 9.7 shows a time normalised plot with two nasals separated by a vowel.

There is clear carry-over nasalisation from the initial nasal extending across the entire length of the intervening vowel. Despite this, there is still a delay in the second peak of nasalisation until well into the second nasal consonant.

9.3.4 Average nasal air-flow separated by vowel environment

When the average nasal airflow ($\bar{U}_n$) is measured separately according to the quality of the preceding vowel (V_1) there are very few observable differences

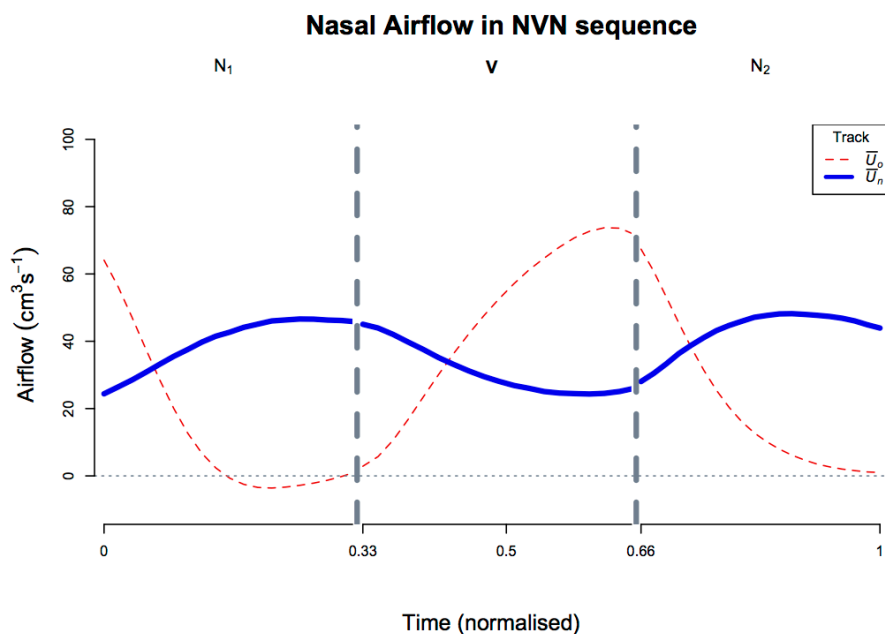


FIGURE 9.7: Average airflow of time normalised N_1VN_2 sequences for all speakers.

shown in the plots. The airflow in nasals does not change very much according to the height of the vowel environments. Average nasal airflow for three places of articulation—bilabial, velar and apico-alveolar—are shown in Figures 9.8 to 9.10 on pages 299–300. There were insufficient tokens at the other places of articulation to separate these according to vowel environment.

All places of articulation, excluding the velar nasals, exhibit complete velic closure in the preceding vowel regardless of the vowel quality. All of the places of articulation have been separated in Figures 9.11 to 9.13 on pages 304–305 and there also the vowel environment is reported on each plot. Figure 9.8 show the bilabial nasals and the nasal flow for two vowels /a/ ([ɐ]) and /u/ ([ʊ])¹. Velar nasals are plotted in figure 9.9 on the next page and contrary what is expected, the low vowel /a/ ([ɐ]) has similar amounts of anticipatory nasalisation to the high vowel /i/ ([ɪ]). The apicals plotted in figure 9.10 show the

¹Shown as /a/ and /u/ respectively in the plots.

Nasal Airflow in /Vm/ sequence

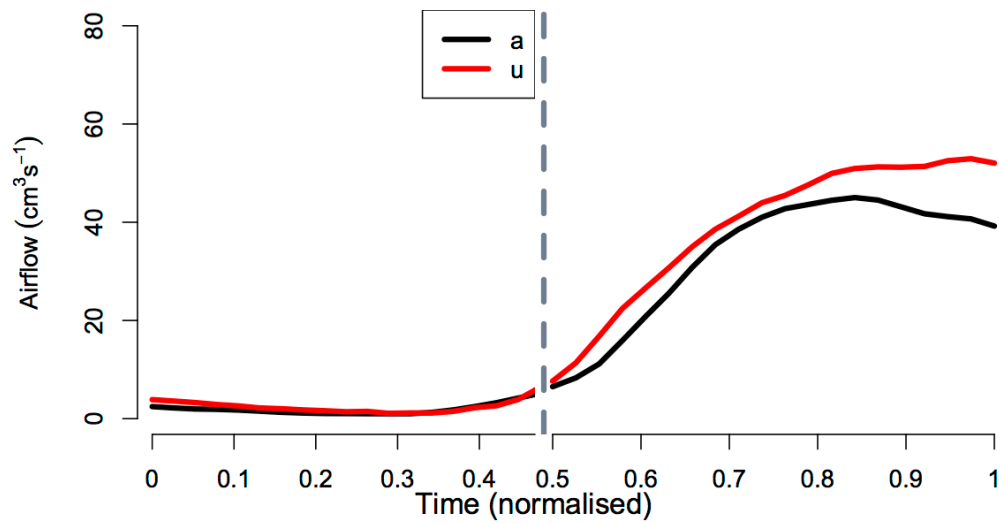


FIGURE 9.8: Average airflow of bilabial nasals in a time normalised sequence of *V* followed by *N* in a *VNV* sequence separated by vowel.

Nasal Airflow in *V*_η sequence

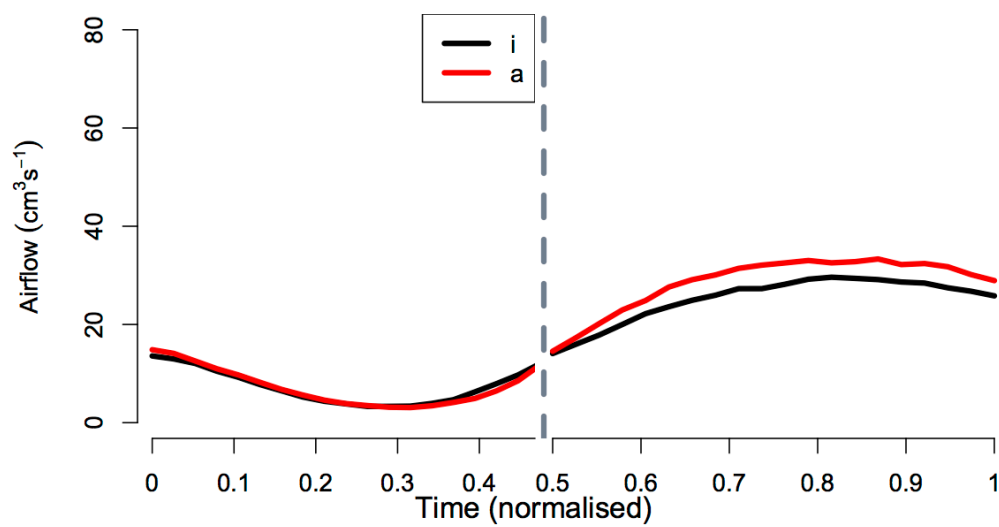


FIGURE 9.9: Average airflow of velar nasals in a time normalised sequence of a *VNV* sequence separated by vowel.

Nasal Airflow in Vn sequence

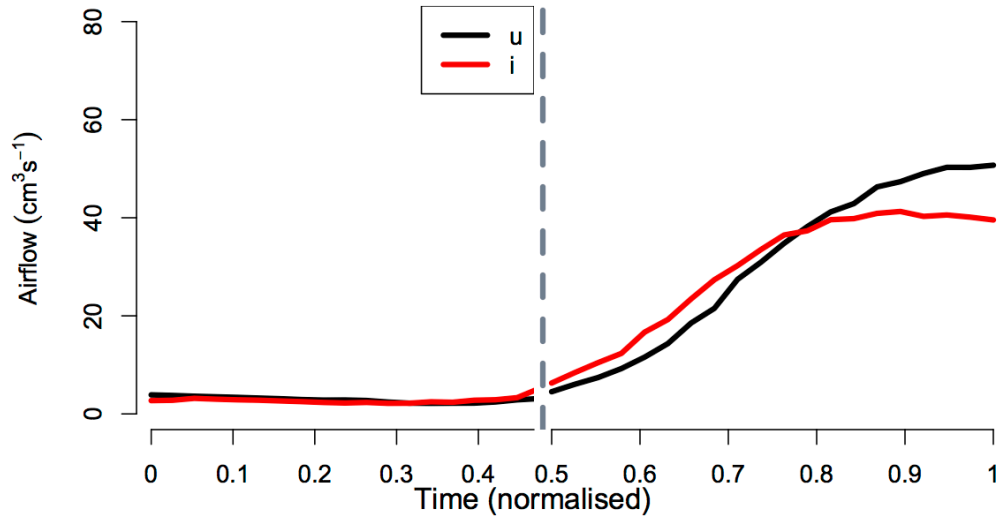


FIGURE 9.10: Average airflow of apico-alveolar nasal in a time normalised sequence of a VNV sequence separated by vowel.

least amount of anticipatory nasalisation of all of the places. Both the palatals and the retroflexes show no evident anticipation of the nasal segment in the preceding vowels.

These averaged and time-normalised measurements show that there is a propensity to delay the opening of the velum until at or after the oral closure. For comparison some tokens are presented without time normalisation or averaging in § 9.5.1 and § 9.6. Prior to this, however, a discussion of average flow in clusters is presented.

9.3.5 Average nasal airflow in clusters

To serve as a comparison to the earlier results involving VNV sequences the averaged oral ($\bar{U}_o$) and nasal ($\bar{U}_n$) flow in cluster environments is summarised (see Tables 9.12 to 9.15 on pages 302–303). The tables are split by place of articu-

lation and also whether the sequence is nasal followed by consonant (VNCV) or consonant followed by nasal (VCNV). Table 9.12 shows that the nasal airflow rises from a low—but not zero—flow value in V_1 , to a peak of nasal-flow in the nasal phoneme (N_1). In C_1 that follows the nasal there is still considerable nasal airflow measurable but by the time of the onset of V_2 the nasal airflow has returned to near zero. The mean oral airflow ($\overline{U}_o$) is reduced within the cluster but in the vowels on either side the flow is at comparable levels to the nasal-flow of vowels in non-nasal environments.

TABLE 9.12: Average Nasal airflow ($\bar{U}_n$) (number of tokens, average and standard deviation) of segments in VNCV sequences (measured in cm³/s).

		Peripheral								Coronal											
										apical								laminal			
		bilabial				velar				alveolar				retroflex				palatal			
VNCV		V ₁	m	C	V ₂	V ₁	ŋ	C	V ₂	V ₁	n	C	V ₂	V ₁	ɳ	C	V ₂	V ₁	j	C	V ₂
	$\bar{U}_n$	6	46	32	7	7	31	16	5	9	36	23	8	—	—	—	—	4	24	12	6
	<i>s.d.</i>	7	32	33	7	5	20	14	5	11	26	16	10	—	—	—	—	5	17	15	3
	<i>n</i>	11				18				39				0				2			

TABLE 9.13: Average Oral airflow ($\bar{U}_o$) (number of tokens, average and standard deviation) of segments in VNCV sequences (measured in cm³/s).

		Peripheral								Coronal											
										apical								laminal			
		bilabial				velar				alveolar				retroflex				palatal			
VNCV		V ₁	m	C	V ₂	V ₁	ŋ	C	V ₂	V ₁	n	C	V ₂	V ₁	ɳ	C	V ₂	V ₁	j	C	V ₂
	$\bar{U}_o$	125	59	62	196	130	104	46	116	122	55	51	135	—	—	—	—	120	38	9	98
	<i>s.d.</i>	58	44	33	100	81	67	29	65	76	40	39	74	—	—	—	—	70	10	9	42
	<i>n</i>	11				18				41				0				2			

TABLE 9.14: Average Nasal airflow ($\bar{U}_n$) (number of tokens, average and standard deviation) of segments in VCNV sequences (measured in cm³/s).

VCNV		Peripheral								Coronal											
										<i>apical</i>								<i>laminal</i>			
										<i>bilabial</i>				<i>velar</i>				<i>alveolar</i>			
		<i>V</i> ₁	C	m	<i>V</i> ₂	<i>V</i> ₁	C	ŋ	<i>V</i> ₂	<i>V</i> ₁	C	n	<i>V</i> ₂	<i>V</i> ₁	C	ɳ	<i>V</i> ₂	<i>V</i> ₁	C	ɲ	<i>V</i> ₂
<i>U</i> _{<i>n</i>}	8	6	32	24	6	7	27	19	10	9	36	30	—	—	—	—	—	—	—	—	
<i>s.d.</i>	10	4	21	15	5	8	27	15	12	9	17	15	—	—	—	—	—	—	—	—	
<i>n</i>	29				13				8				0				0				

TABLE 9.15: Average Oral airflow ($\bar{U}_o$) (number of tokens, average and standard deviation) of segments in VCNV sequences (measured in cm³/s).

VCNV		Peripheral								Coronal										
										<i>apical</i>						<i>laminal</i>				
										<i>alveolar</i>				<i>retroflex</i>		<i>palatal</i>				
		<i>bilabial</i>				<i>velar</i>														
V ₁	C	m	V ₂	V ₁	C	ŋ	V ₂	V ₁	C	n	V ₂	V ₁	C	ɳ	V ₂	V ₁	C	ɲ	V ₂	
$\bar{U}_o$	179	82	42	106	144	62	46	111	162	146	41	89	—	—	—	—	—	—	—	—
<i>s.d.</i>	98	39	34	77	74	59	32	70	81	90	24	50	—	—	—	—	—	—	—	—
<i>n</i>	27				13				10				0				0			

The following plots displayed in Figures 9.11 to 9.13 on pages 304–305 and Tables 9.12 to 9.13 on page 302 show mean nasal and oral flow in VCNV sequences, separated by place of articulation. The bilabial [m], velar [ŋ] and apico-alveolar [n] nasals in VCNV sequences are plotted in Figures 9.14 to 9.15 on page 306. There are no examples of clusters involving retroflexes or palatals for this sequence of segments in the corpus.

The plot in Figure 9.14 on page 306 shows nasal flow in a /VCNV/ sequence (measured in $\text{cm}^3 \text{s}^{-1}$), where the nasal is bilabial. These are both heterorganic and homorganic clusters. It is clear from the Figure that again there is minimal anticipatory nasal airflow, yet there is greater carry-over nasal flow in V_2 . The time normalisation does not show the relative durations of the oral stop to nasal.

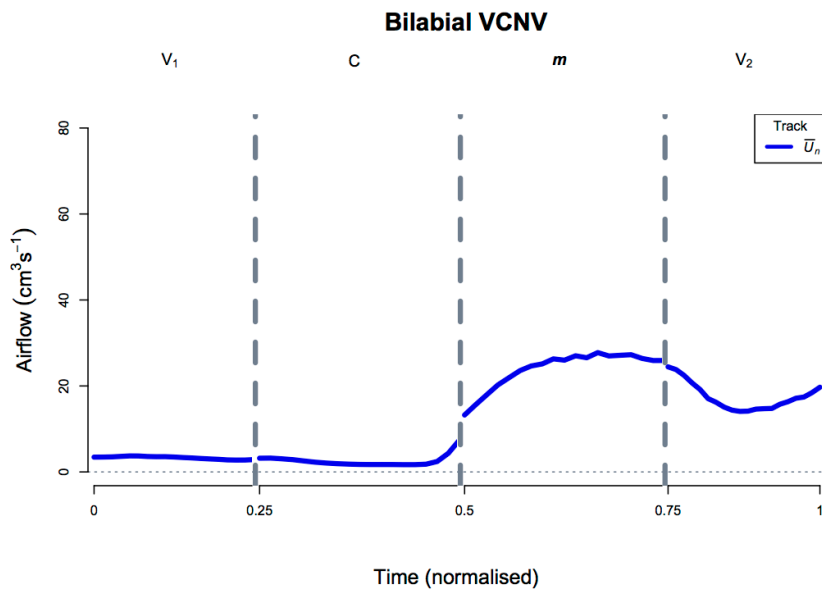


FIGURE 9.11: *Airflow of bilabial nasals in a time normalised sequence VCNV for all speakers.*

There is some anticipation in some cluster environments: Nasal airflow increases marginally earlier in /VCNV/ sequences (shown in Figure 9.13). This is presumably due to the preceding voiceless consonant and consequently no need to suppress nasalisation to preserve place of articulation cues.

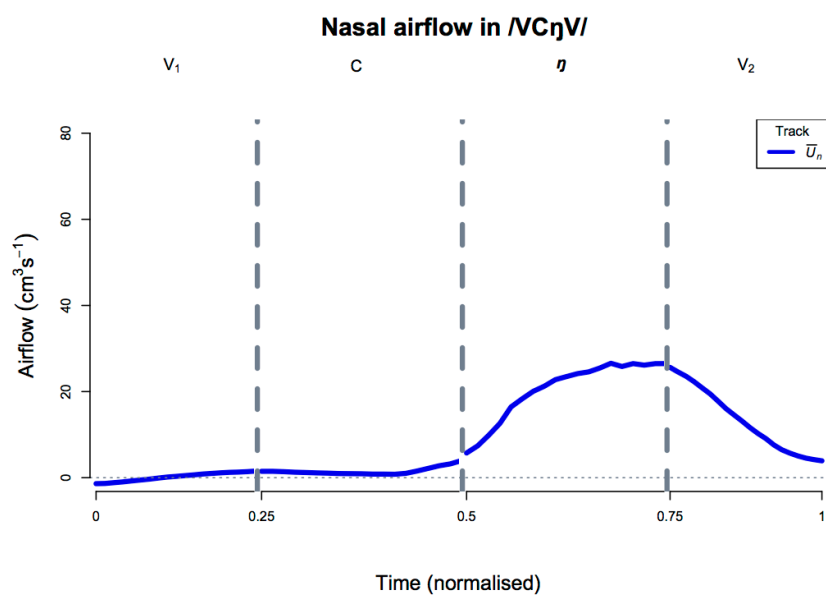


FIGURE 9.12: Airflow of velar nasals in a time normalised sequence VCNV for all speakers.

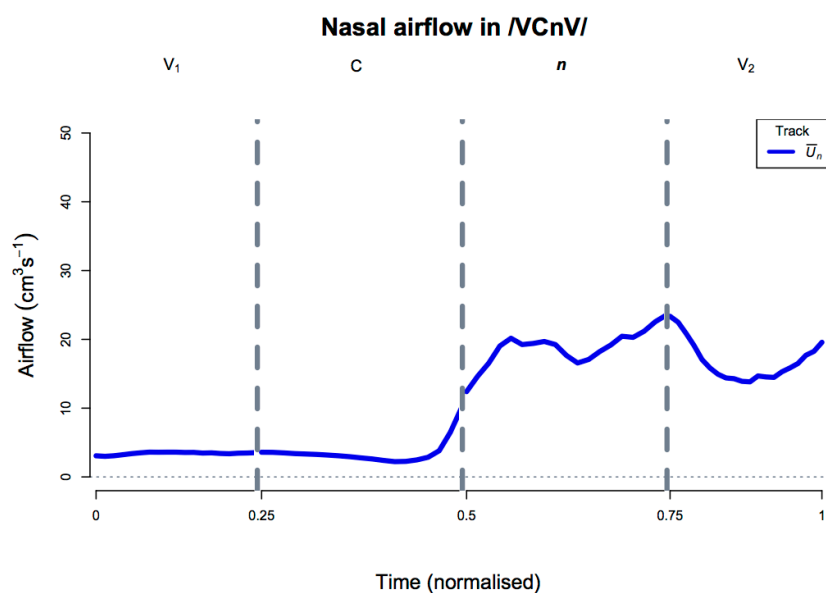


FIGURE 9.13: Airflow of apico-alveolar nasals in a time normalised sequence VCNV for all speakers.

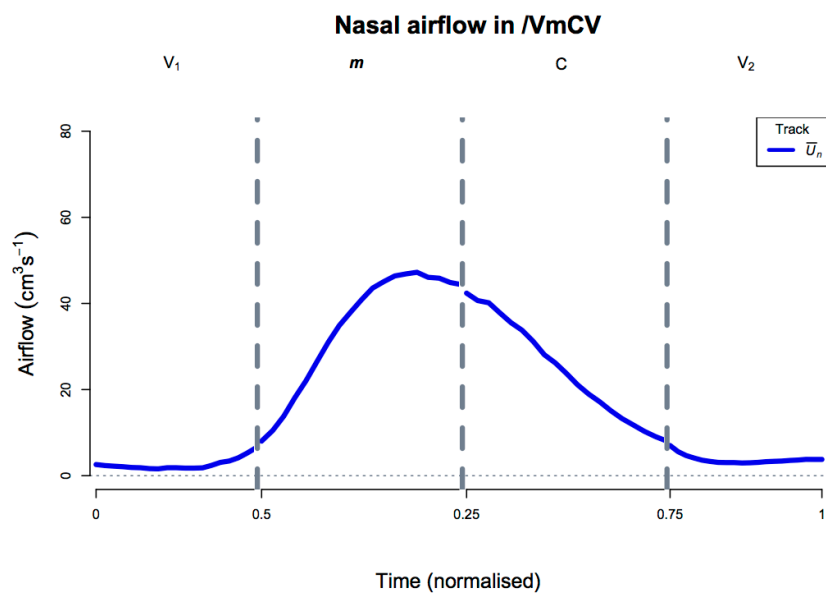


FIGURE 9.14: Average airflow in a time normalised VmCV sequence for bilabial nasals averaged across all speakers.

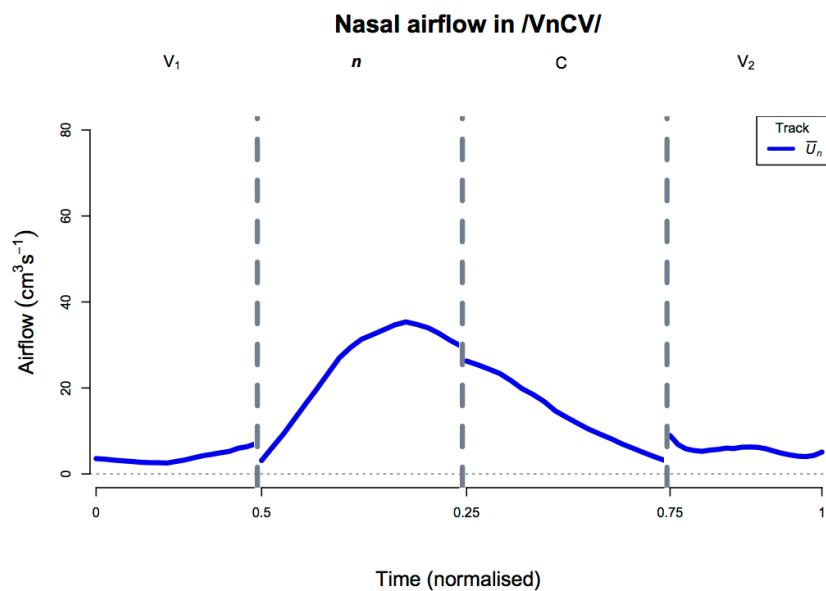


FIGURE 9.15: Airflow in a time normalised VnCV sequence for apico-alveolar nasals averaged across for all speakers.

9.4 Nasal timing, anticipation, delay and carry-over nasalisation

9.4.1 Anticipation and delay of nasalisation

Figure 9.16 shows the duration of anticipation and delay in milliseconds from all measured speakers. The measurements follow a similar methodology to the experiment conducted by Basset and colleagues regarding nasalisation in French (Basset et al., 2002) discussed earlier in the method (§ 5.9.4). The three sequences measured include a singleton nasal between two vowels (VNV), a cluster of a nasal followed by a stop also between two vowels (VNCV) and a cluster of a stop followed by a nasal between two vowels (VCNV). In the case of the clusters it has been assumed that there is a morpheme boundary between the nasal and the stop in each case based on Evans' (2003) grammatical analysis. However a morpheme boundary cannot be assumed for intervocalic singleton nasals. The number of tokens is re-expressed as a percentage of the total number of tokens in Table 9.16. Of the total there are 73% that have anticipatory nasal airflow and 27% that have a delay in the nasalisation. This can be compared with the levels of pre-stopping as measured from the acoustic signal alone on in Table 9.6 on page 285.

TABLE 9.16: *Percentage of tokens with anticipated and delayed nasalisation.*

	Anticipation		Delay
	N	(%)	(%)
VNV	74	77	23
VNCV	88	72	28
VCNV	60	67	33

The durations of both anticipation and delay are so short that the onset of the nasal air flow could be described as synchronous to the oral closure (at

or below a “just noticeable difference”) which, based on perceptual studies of complex auditory stimuli, can be assumed to be approximately 30 ms (Pastore & Farrington, 1996; Pisoni, 1977)). Apparently the velum is lowered very quickly in these examples which does not fit with previous description of the velum as a sluggish articulator (Ohala, 1975; Stevens, 1998, p. 43). The sole place of articulation with examples that deviate from this almost synchronous co-ordination of the articulators are velar nasals, which as previously noted can be allophonically uvular in some environments (as shown in Figure 9.6). Any articulation that incorporates the soft palate or velum as the secondary or passive articulator could possibly interfere with velar lowering. This could also be exacerbated in a front, high vowel environment where there is a true velar place of articulation, for example the word *kinga* ‘estuarine crocodile (*Crocodylus porosus*)’. The results below provide a more thorough description of velar nasals.

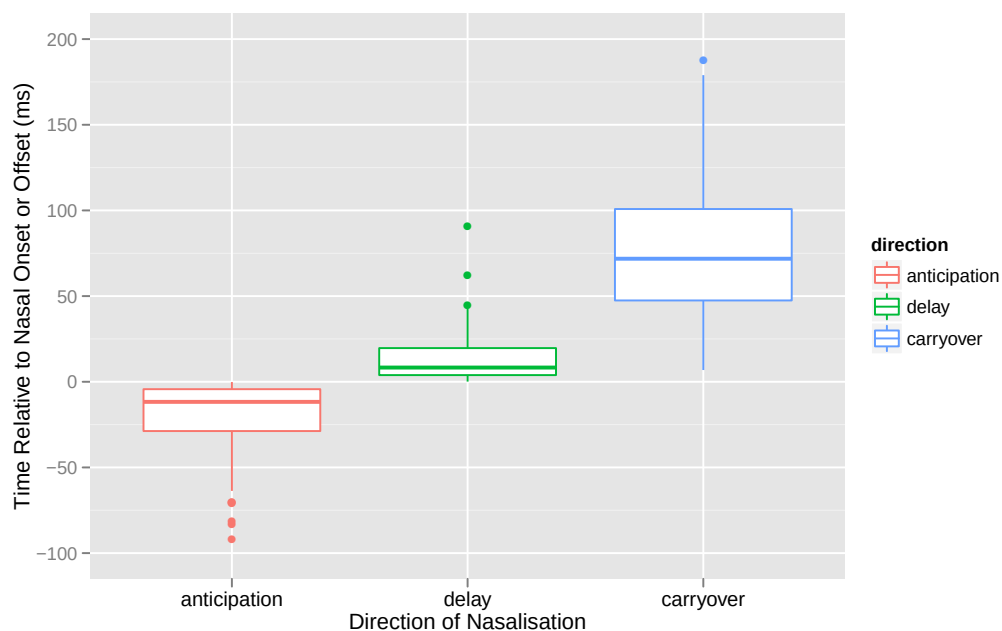


FIGURE 9.16: The duration of anticipation (a), delay (d) and carry-over (c) relative to the onset or offset of a nasal.

The amounts of carry-over exceed the levels of anticipatory nasalisation.

A LMEM ($\chi^2(6, N = 435) = 227, p < .001$) shows that a main effect of directionality of nasalisation (anticipation, delay or carry-over) (fixed factor) has a statistically significant duration effect (with speaker and token included as random effects). A *post hoc* Tukey multiple comparison of means test shows that the mean of the Anticipation (a) differs from the mean of the Delay (d) by 28 ± 8 ms ($p = .004$), significant at a 1% (99% confidence). Carryover (a) is 109 ± 6 ms greater than Anticipation ($p > .001$) and carry-over is 81 ± 8 ms ($p > .001$) greater in duration than delay. As discussed above, the mean anticipation and delay prove to be short enough to be considered co-incident. Figure 9.17 shows that the pattern is consistent across speakers.

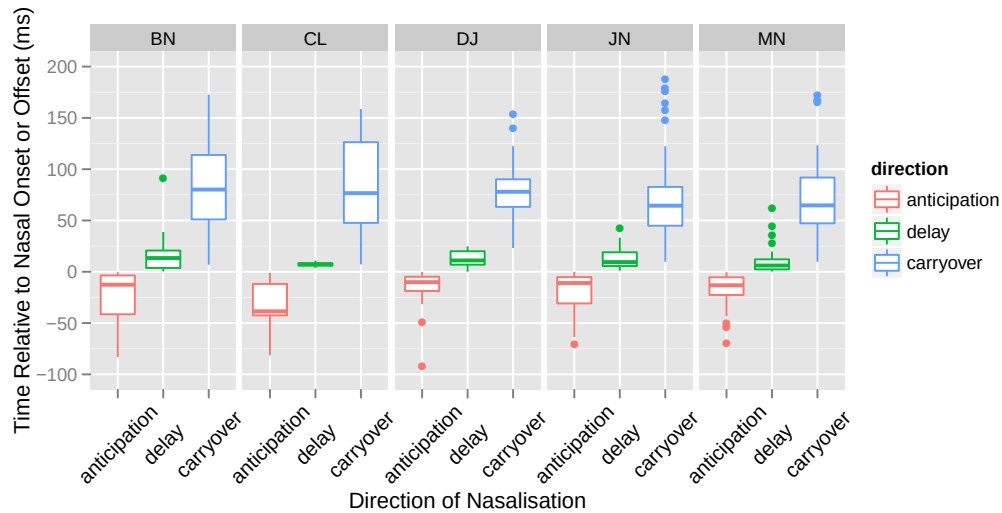


FIGURE 9.17: The duration of anticipation (a), delay (d) and carry-over (c) relative to the onset or offset of a nasal separated by speaker.

The ratios of anticipation and carry-over to the surrounding segments show that the effects of carry-over are far greater than the effects of either anticipation or delay (see Figure 9.18). Each of the panels shows a different speaker and The first two boxes (a and d) show the ratio of Anticipation duration or Delay duration to the previous segment (N-1) and the third box (c) in each panel shows the ratio of Carryover to the following segment (N+1). The very small differences between Anticipation and Delay may be explained by differences in

place of articulation, however this has not been confirmed statistically.

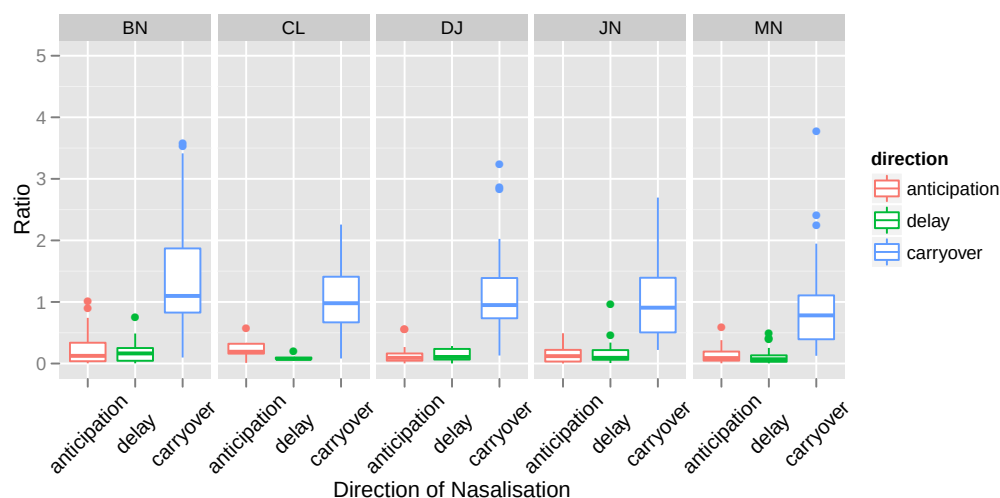


FIGURE 9.18: The ratio of anticipation (a), delay (d) to the segment preceding a nasal and carry-over (c) relative to the segment following a nasal separated by speaker.

9.5 Nasal timing in singletons and clusters

As discussed above in § 9.3.5, the time normalisation obscures the timing differences shown between different cluster types. The durations that are based exclusively on acoustic data are shown in Tables 9.4 to 9.5 on pages 281–282. The plots below show nasal airflow results in single intervocalic nasals and also in both homorganic and heterorganic clusters.

9.5.1 Single nasals

The single nasals show a delay in the rise in airflow for most speakers when compared with the onset of oral closure. This is not always the case as shown below in the word *kamak* (in Figure 9.19), which shows very slight anticipation.

The time from the oral closure until the maximum rate of flow (U_n^{MAX}) is always positive—showing that the nasal airflow rises at the fastest rate only after oral closure has been made. This suggests that the the velum opens in two distinct stages (as shown by Bell-Berti & Krakow, 1991; Bladon & Al-Bamerni,

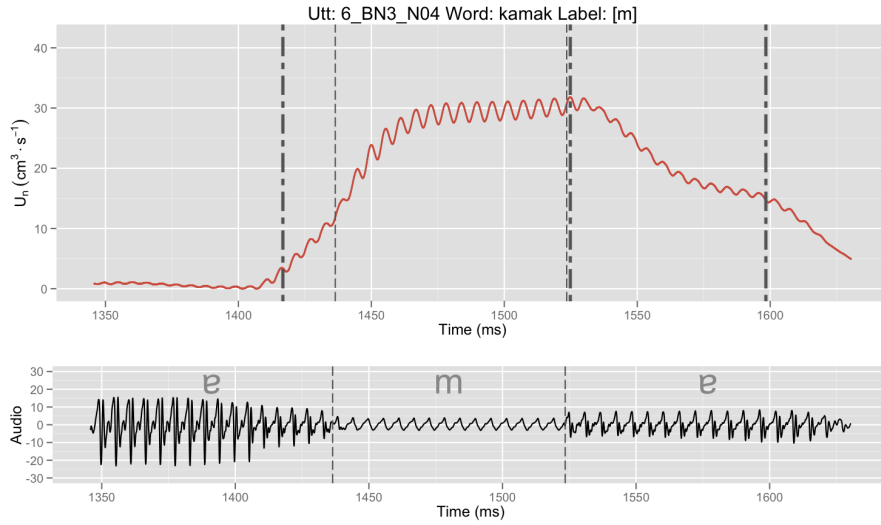


FIGURE 9.19: Nasal (U_n) air flow and acoustic waveform for a VNV sequence in the word kamak ‘good’.

1982). In Biniñ Gun-wok, the first stage of lowering may be almost instantaneous but the second stage shows a rapid airflow rise quickly reaching the nasal-flow maximum (U_n^{MAX}). This suggests that, in this second stage of lowering, the velum opens relatively rapidly. If the velum is a sluggish articulator it may need an aerodynamic component for this rapid velum lowering to be realised. When a nasal is word initial this associated rapid rise is not observed, however.

The results of an LMEM ($\chi^2(6, N = 336) = 17.4, p < .001$) shows that the mean time until the maximum rate of change in the nasal airflow ($f'(U_n)$), is the same, when sequence structure in single nasals (VNV) and also nasal stop clusters (VNCV) are included as a two-tiered fixed factor (a non-significant difference of $p = 0.296$). This is shown as a dashed blue line in Figure 9.24 showing the word *bebmeng*)

When a cluster of a stop followed by a nasal (VCNV) is measured, the time until the maximum rate of change in nasal airflow is delayed by approximately

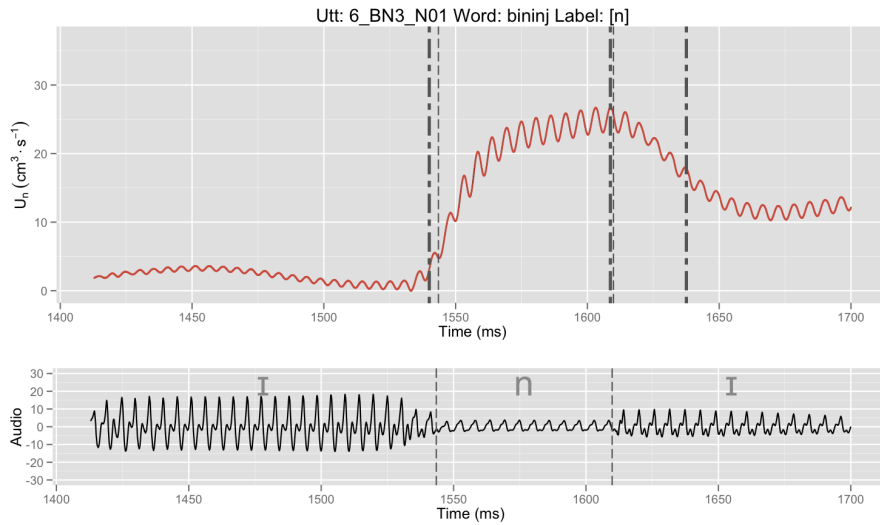


FIGURE 9.20: Nasal (U_n) air flow and acoustic waveform for a VNV sequence in the word *bininj* ‘man’.

140 ± 32 ms ($p < .001$). This duration difference is not dependent on the place of articulation. The differences in the distribution across speakers are shown in Figure 9.21.

The following section examines the internal structure of nasal stop clusters in greater detail.

9.6 Clusters involving nasals

The heterorganic VNCV sequences show a very strong nasal airflow peak and a rise in airflow that is delayed with respect to oral closure (see Figure 9.22 showing the word *lonbom*). The figure shows a time until ($f'(U_n)$) of under 30 ms and a time until maximum flow of about 75 ms. When examined statistically with a LMEM ($\chi^2(6, N = 336) = 43.8, p < .001$), including fixed effect of sequence structure (VNV, VCNV and VNCV) and speaker and token as random factors is significantly different (summarised in Figure 9.23).

The time until the maximum airflow rate flowing through the nasal cavity

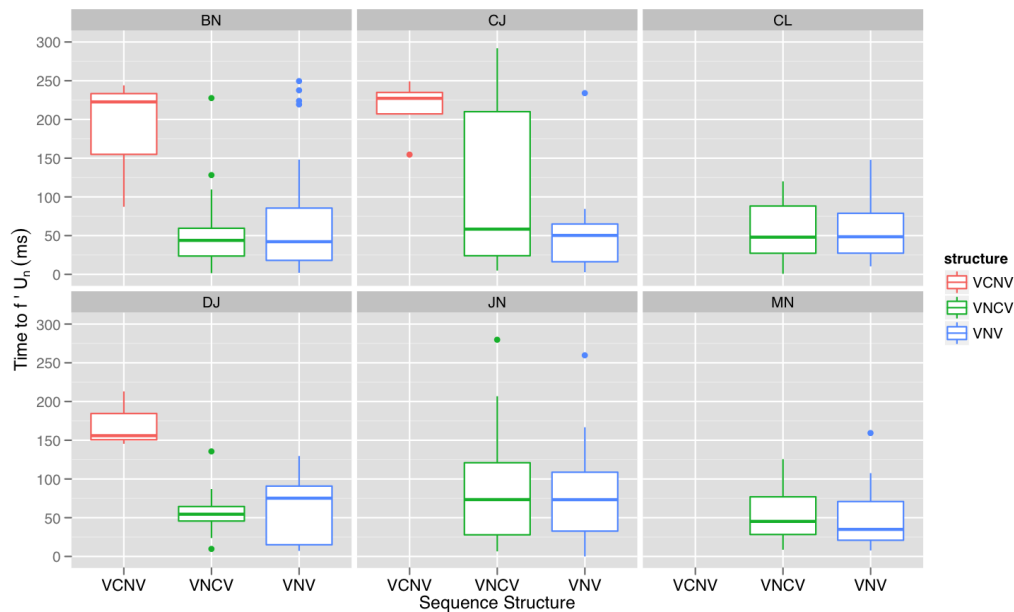


FIGURE 9.21: The time from the oral closure until the maximum rate of change in the nasal flow rate ($f'(U_n)$) (ms) separated by speaker.

(U_n^{MAX}) is different for VNV sequences and VCNV sequences ($p < 0.001$). A difference is also shown between a VNCV and VCNV sequence ($p < 0.001$). There is no significant difference, however in the mean maximum airflow rate in VNV sequences and VNCV sequences. In this example the nasal is long in duration and the stop is short although there may be small amounts of coproduction with the lips closed before the apical closure is released (see § 9.6.2 below)

Stops followed by nasals in intervocalic environments (VCNV), have nasals with very short acoustic durations and stops with relatively long durations (see Table 9.5 on page 282). This is supported by aerodynamic evidence (see Figure 9.24 and Figure 9.25). Both homorganic and heterorganic clusters have very long, voiceless oral stop closures. This makes them very reminiscent of fortis stops in terms of voicing profile and duration (see Chapter 6). Figure 9.24 shows Nasal airflow (U_n) in an homorganic stop followed by nasal cluster en-

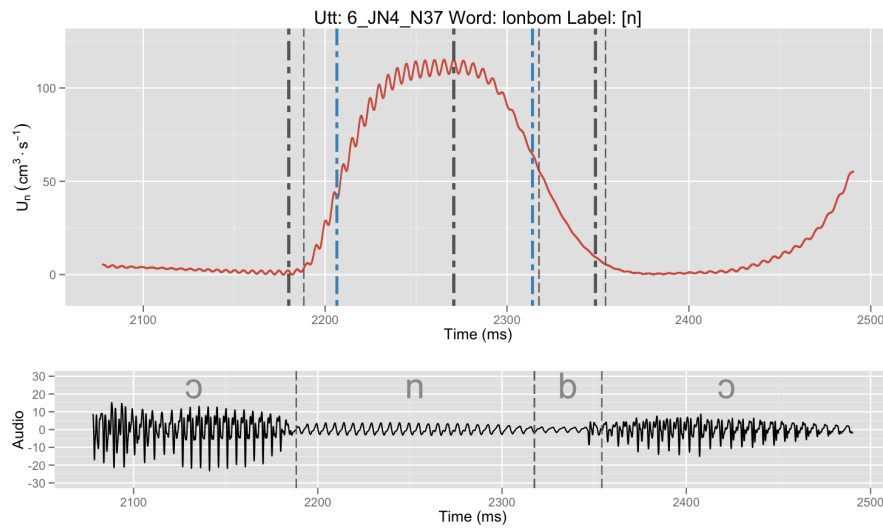


FIGURE 9.22: Nasal (U_n) air flow and acoustic waveform for an heterorganic nasal plus stop cluster (VNCV).

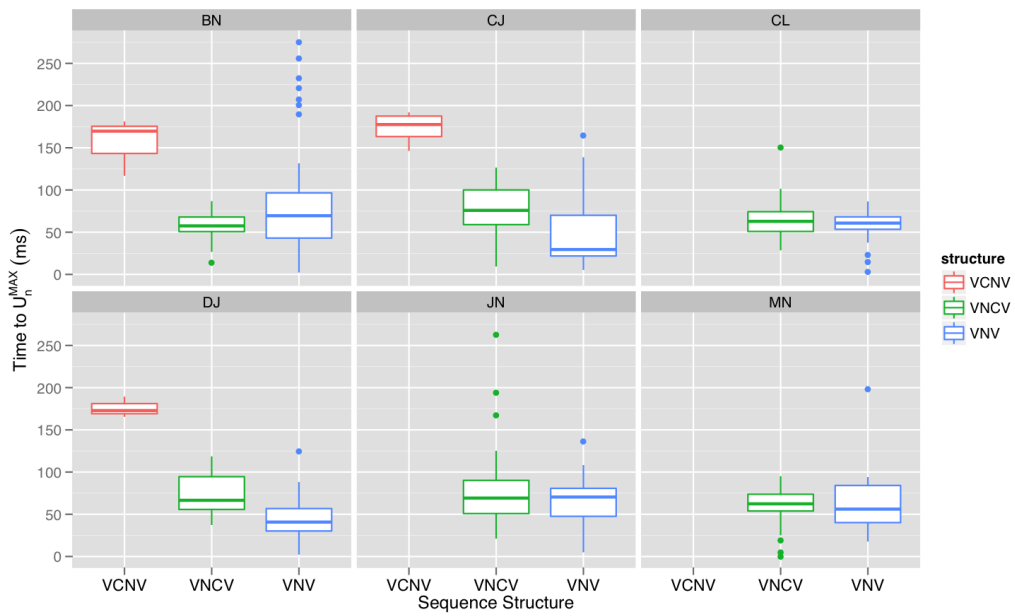


FIGURE 9.23: The time from the oral closure until the maximum flow rate (U_n^{MAX}) (ms) separated by speaker.

vironment (VCNV).

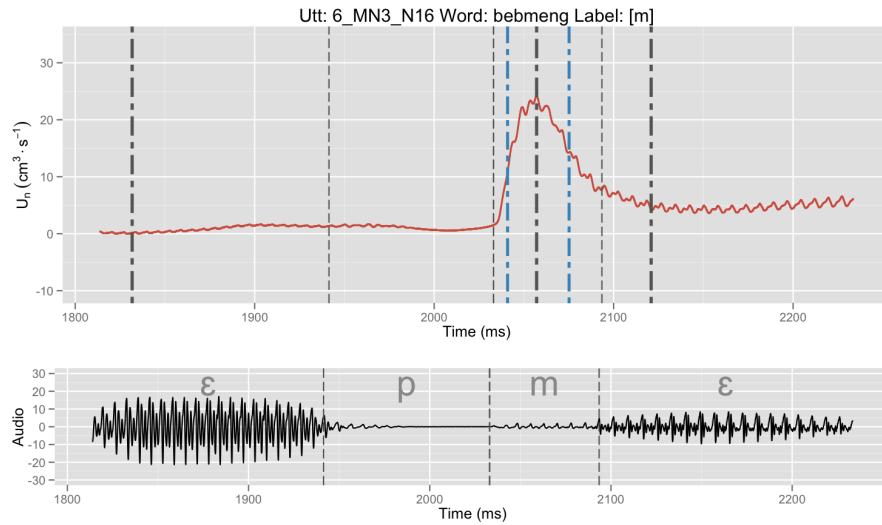


FIGURE 9.24: Nasal (U_n) air flow and acoustic waveform for an homorganic stop plus nasal cluster (VCNV).

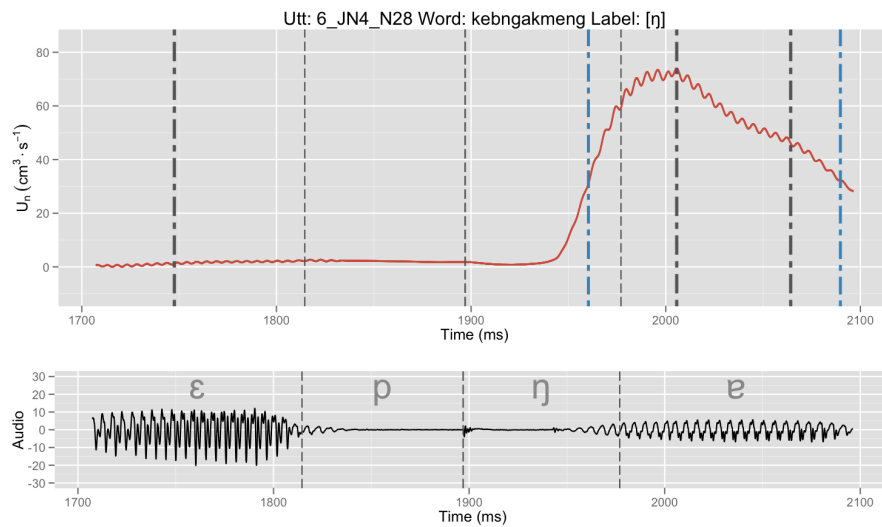


FIGURE 9.25: Nasal (U_n) air flow and acoustic waveform for an heterorganic stop plus nasal cluster.

In the heterorganic example (Figure 9.25) the start of the airflow rise is voiceless and voicing only commences just prior to the release of the oral occlusion. The airflow peak (shown just after 2000 ms) is well into the following vowel.

9.6.1 A cluster of nasal followed by a stop

Looking at the stop + nasal cluster environment in more detail shows that the medial stop environment is strengthened with respect to the following nasal for both VNCV and VCNV sequences.

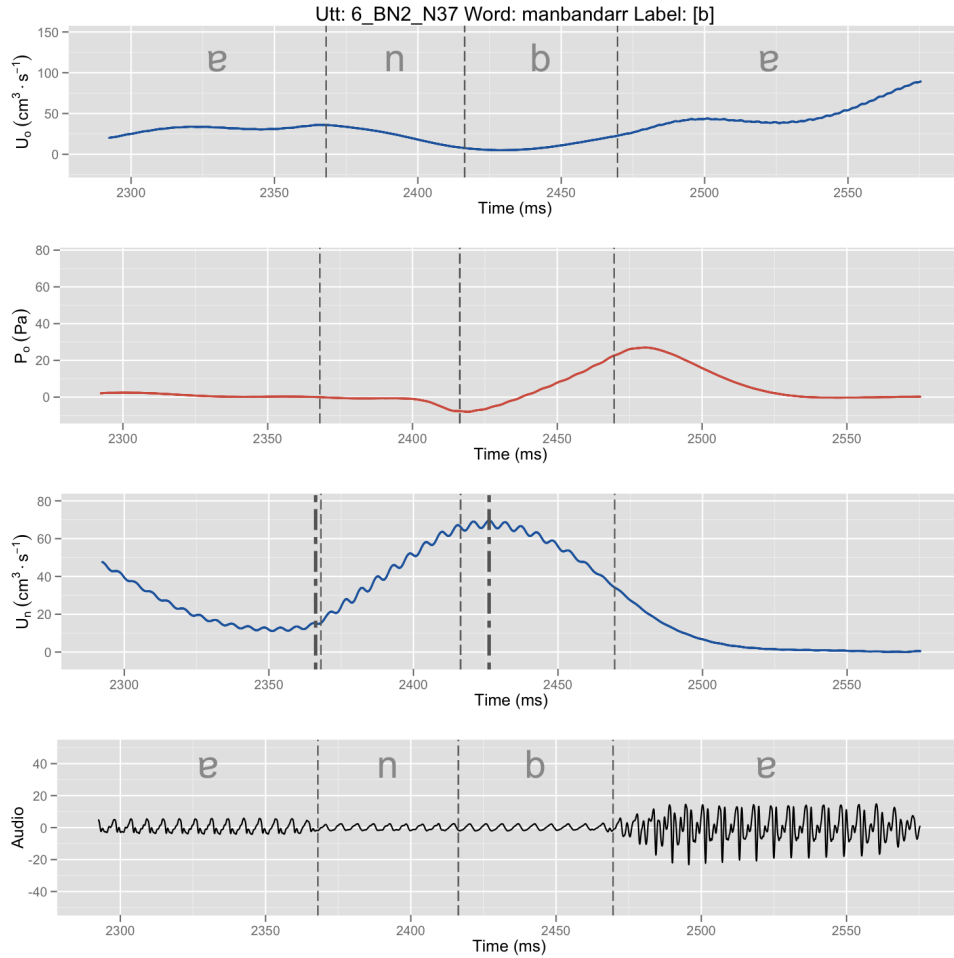


FIGURE 9.26: Oral (U_o) and nasal (U_n) air flow, intra-oral pressure (P_o) and acoustic waveform for an heterorganic stop plus nasal cluster (VNCV) in the word manbandarr speaker BN.

In Figure 9.26 the central panels show intra-oral pressure (P_o) and nasal air flow (U_n) respectively in a CN heterorganic cluster. The nasal airflow extends across the entire duration, with the airflow peak after the middle of the cluster duration at approximately 75 ms (shown at 2427 ms in the figure). The intra-oral pressure is delayed with respect to the nasal. As there is apico-alveolar

occlusion the intra-oral pressure cannot be measured until after the release of the [n]. The peak nasal airflow is also relatively high at over 60 cm s^{-1} .

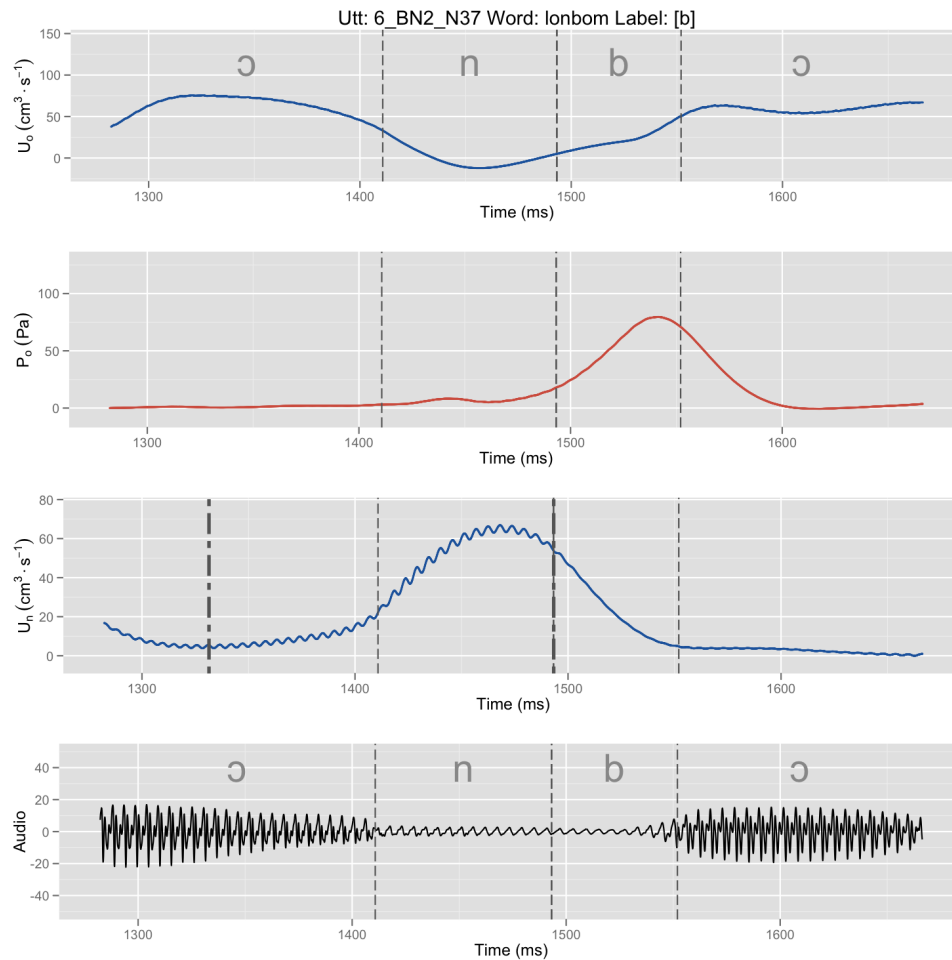


FIGURE 9.27: Oral (U_o) and nasal (U_n) air flow, intra-oral pressure (P_o) and acoustic waveform for an heterorganic stop plus nasal cluster (VnbV) in the word lonbom, speaker BN.

A similar pattern is found in Figure 9.27 for the same speaker BN. There are no examples of homorganic clusters with intra-oral pressure records however.

9.6.2 A cluster of stop followed by a nasal

The stop followed by a nasal forming a heterorganic cluster shows the stop is voiceless and with a relatively high intra-oral pressure. The nasal airflow starts almost at the start of the oral occlusion in this example however. The onset of

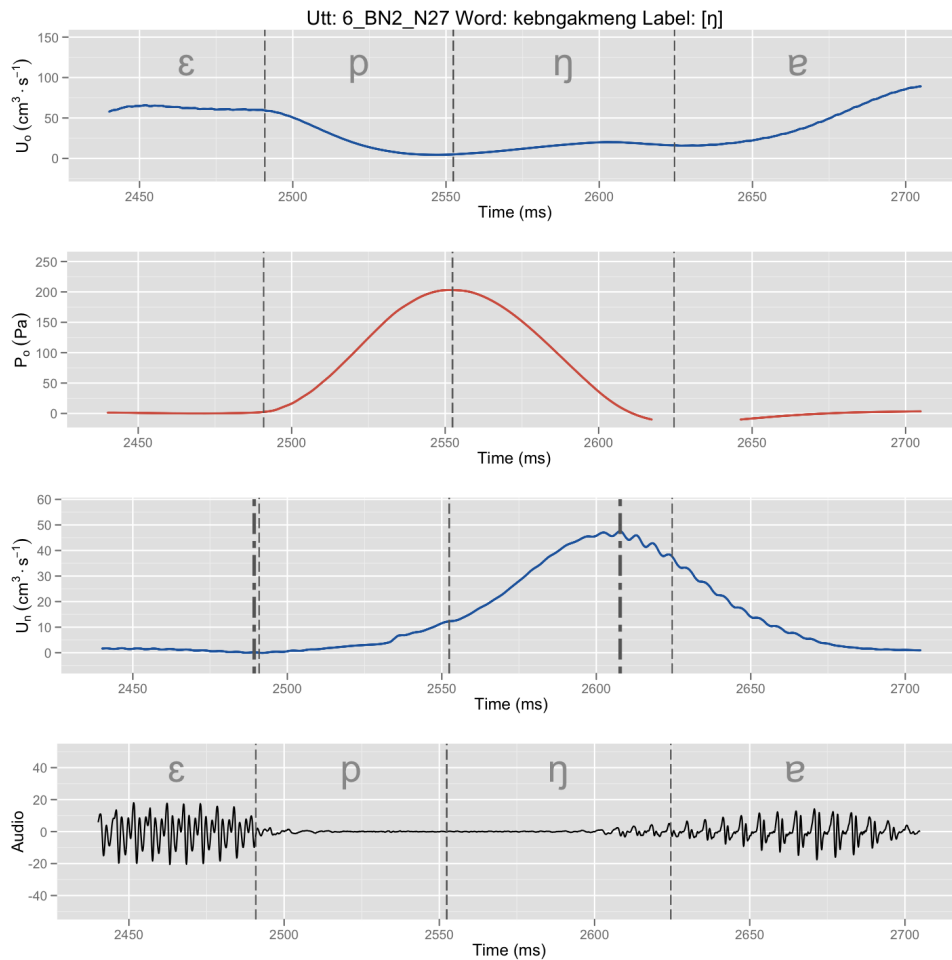


FIGURE 9.28: Oral (U_o) and nasal (U_n) air flow, intra-oral pressure (P_o) and acoustic waveform for an heterorganic stop plus nasal cluster ($Vp\eta V$) in the word *kebngakmeng*, speaker BN.

the nasal is truncated.

In a homorganic stop followed by nasal sequence, as shown in Figure 9.29, the nasal has a very short duration and in addition has a relatively low airflow. The stop has a long duration and again voiceless for the majority of closure.

For a different speaker (DJ) there is more overlap between the two adjacent segment in this heterorganic sequence (shown in Figure 9.30). All of the examples, although largely qualitative, show that there is a delay in the nasal peak

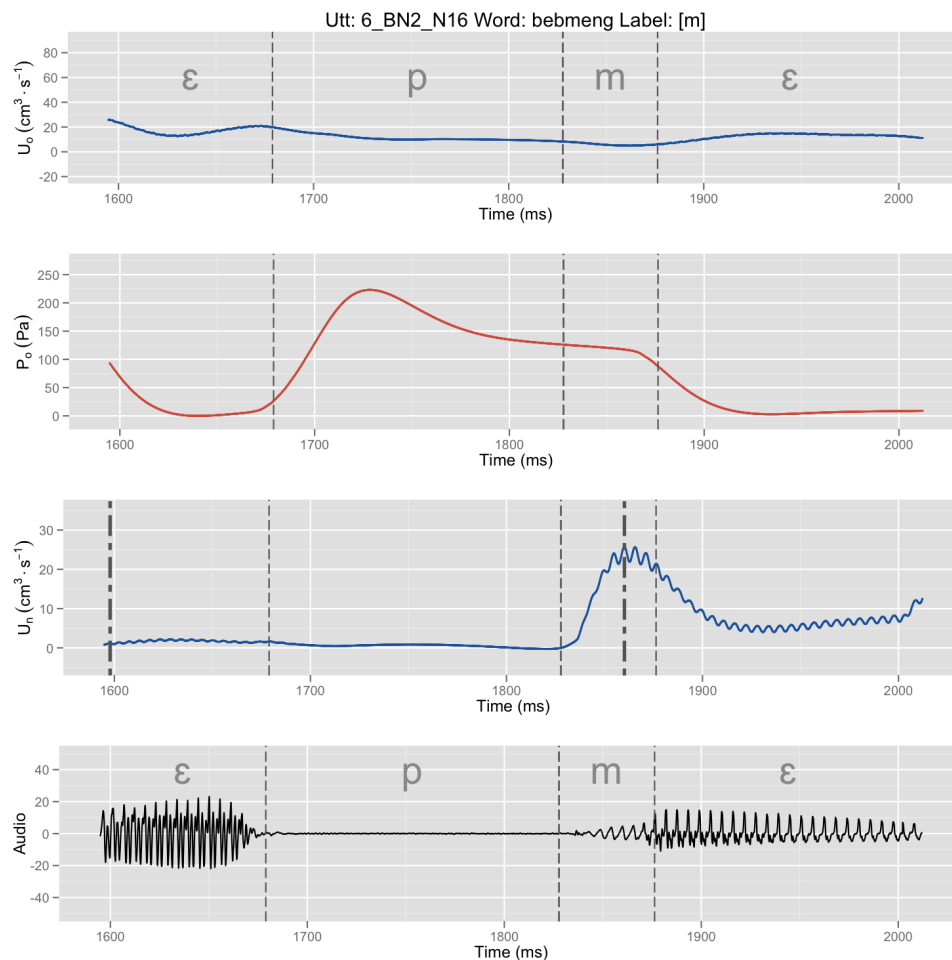


FIGURE 9.29: Oral (U_o) and nasal (U_n) air flow, intra-oral pressure (P_o) and acoustic waveform for an homorganic stop plus nasal cluster (VpmV) in the word bebmeng, speaker BN.

for all environments in which the nasal is found. The nasal is far stronger both in terms of duration and also maximum nasal airflow in the initial N_1 position of a N_1C_2 cluster. The carry-over nasalisation is not under active control in these environments. Although not shown in this chapter, final glottal stops also abruptly extinguish carry-over nasal flow.

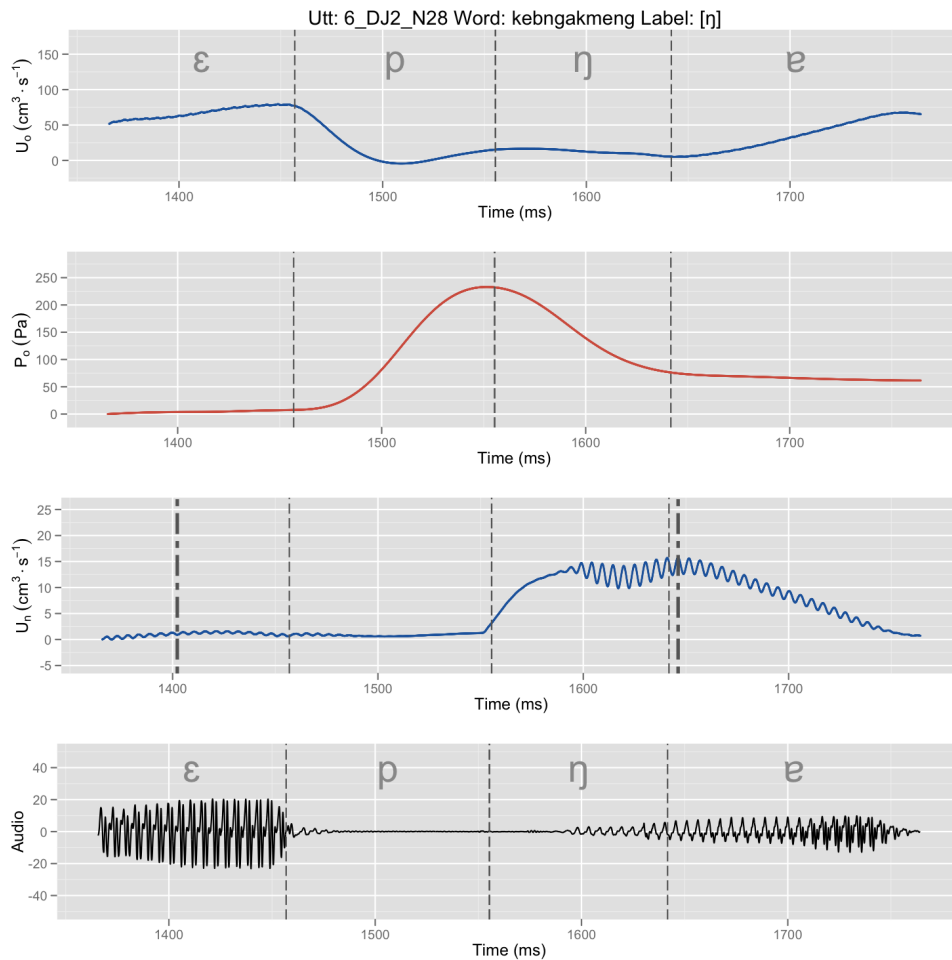


FIGURE 9.30: Oral (U_o) and nasal (U_n) air flow, intra-oral pressure (P_o) and acoustic waveform for an heterorganic stop plus nasal cluster ($Vp\eta V$) in the word *kebngakmeng*, speaker DJ.

9.7 Discussion

Each of the measurement techniques used supports the first hypothesis (H1 in § 9.1 on page 276): that the lowering of the velum is delayed with respect to the oral closure in nasal stops. This occurs in both intervocalic singleton nasals and also nasals adjacent to stop in cluster environments. The velum does not close again with such rapidity in following vowels however. Nasals occur frequently in both onset and coda positions of syllables and morphemes. The

measurements of Anticipation, Delay and Carryover with respect to the acoustic landmarks of the nasal show that both anticipation and delay are within 30 ms of the closure in the oral cavity and they do not differ significantly from one other. The carry-over nasal flow, in contrast, has an average duration above 70 ms (see § 9.4.1 for results).

The second hypothesis (H2) is also supported. Nasal followed by stop clusters (VNCV in this analysis) pattern very differently to clusters involving stops followed by nasals (VCNV). The time normalised results shown in § 9.3.5 obscure the fact that stop durations are more than double the nasal duration in VCNV sequences (see Figure 9.25 and 9.24) whereas in a VNCV sequence the nasal has a longer duration (see Figure 9.22). The nasal airflow pattern is also truncated in a VCNV sequence, with a more rapid rise and fall in nasal airflow with a lower maximum flow rate.

The stops preceding nasals in VCNV sequences are almost always voiceless and although the durations are not as long they have many of the characteristics of fortis stops (see Chapters 6 and 7).

The medial position shows strengthening in both stops and nasals. Duration is greater in the C_1 position of a cluster for both oral stops and nasals. There is a delay in the second gesture that can be inferred from both nasal airflow and intra-oral pressure.

Vowel environment is known to play a role in the amount of anticipatory nasalisation. High vowels are said increase the amount of anticipatory nasalisation. This vowel effect is not shown to be significant in Bininj Gun-wok and there is much greater influence of the place of articulation of the nasal, in particular velar nasals.

In summary, the results show that a word with an initial non-nasal has the velo-pharyngeal port tightly closed until the last possible moment before or slightly after the oral closure in a following nasal. The average nasal flow rates are considerably lower than averages in English reported by Warren, Dalston,

and Mayo (1993), at between $80 \text{ cm}^3 \text{ s}^{-1}$ to $200 \text{ cm}^3 \text{ s}^{-1}$ for Bininj Gun-wok. This could be due to the late opening of the velum, suggesting that the gesture is truncated and consequently that there is not enough time for the port to open as wide as in a language such as English with significant anticipatory nasalisation giving time for full velar opening.

When considered cross-linguistically the velo-pharyngeal system and the directionality of nasality in Bininj Gun-wok is not unusual. The lack of anticipatory nasalisation are comparable to phonemically non-nasalised vowels in French. French also has similar levels of carry-over nasalisation in VNV sequences, but far greater levels of anticipatory nasalisation in most other contexts (Basset et al., 2002). In other languages Farnetani and Kori (1986), found that nasals in Italian have more nasality in the following vowel than in the preceding one. Many Austronesian languages also show phonemic prestopping which may indicate a similar delay in velum opening (Riehl, 2008).

The final figures in this chapter show that there is a pressure rise within oral cavity which is then rapidly released. The pressure release coincides with a lowering of the velum. This occurs very rapidly as has been noted previously by Schebeck (cited by Carroll (1976:13)) in Bininj Gun-wok (see § 4.1).

Chapter 10

Conclusion

This thesis constitutes the first major physiological study of acoustic and articulatory patterns in medial stops and nasals for the Australian language Bininj Gun-wok. At the core is a quantitative study consonant articulation using statistical methods to support the phonetic analysis of an Australian language. The medial position is crucial to the study as this is where the majority of contrast in Australian languages are found.

The central finding of this research is that in Bininj Gun-wok, as in other languages, duration is indeed a major phonetic cue to differentiating between two stop series that do not otherwise contrast for voicing. A further important observation, based on durational results, clearly demonstrated that voice onset time does not play a role in signalling the contrast. Similar results have been found in languages related to Bininj Gun-wok such as Jarwoyn (Jaeger, 1983), Rembarrnga (McKay, 1980) and Ngalakgan (Baker, 2008; Merlan, 1983). This study draws upon a much larger corpus of data containing many speakers with a wide range of ages. The quantitative analysis of these data supports many of the previous observations about medial stops particularly regarding duration. The secondary finding is that the nasalisation is under active control with respect to anticipatory timing, similar to Italian and French (Basset et al., 2002; Cohn, 1990; Delvaux et al., 2008). In Bininj Gun-wok, the velum is lowered

coincidentally or just after the oral occlusion. This restriction is clearly somehow under speaker control but this is not the case for carry-over nasalisation. When the results from the experiments are considered together, the findings confirm that the medial position is one of relative strength in the phonology of the language.

10.1 Lenis and fortis medial stops in Bininj Gun-wok

The first two experiments provide evidence for phonetic differences between the two stop categories and furthermore they differentiate between fortis stops—which are found within morphemes—and homorganic sequences—like geminates, which cross morpheme boundaries. As described in the phonological introduction, Bininj Gun-wok is a polysynthetic language. Additionally it has an agglutinative morphology and consequently there are many clusters formed at morpheme boundaries that contain both stops and nasals making it an ideal language to control for place of articulation dependent effects.

Bininj Gun-wok shows a relatively high number of place of articulation contrasts when compared cross-linguistically; the acoustic correlates of the cavity size differences are measurable and highly stable across speakers. The timing differences may relate to place of articulation with corresponding changes in cavity size behind the oral occlusion. This supports many of Butcher's observations and lends weight to the place of articulation imperative theory (Butcher, 2006a, forthcoming).

Total consonant duration is a consistent phonetic difference between lenis and fortis categories. In addition Voice termination time is an observed difference. The duration differences of VTT are likely to be far too short to be perceptibly different, however. Despite the short duration of these VTT measurements, they may signal different articulatory strategies between the stop categories.

Voice onset time did not show to be a source of difference between the stop categories. Some lenis stops were fully voiced were categorised with a negative VOT but the stops of both categories showed positive VOT values that were similar but place of articulation dependent.

There was also only a weak statistical correlation with preceding vowel duration. The duration of vowels preceding lenis stops is only 12 ms greater than the vowels preceding fortis stops. The shortening of a vowel before a voiceless segment—termed pre-fortis clipping—is commonly reported in English (Lisker, 1974), yet this effect is not consistently found in Bininj Gun-wok. This is similar to results found in Jarwoyn (Evans & Merlan, 2004).

There are further differences between lenis and fortis stops beyond duration. In order to extend the analysis of medial stops, articulatory data—aerodynamic and electroglottographic information—were included. The contrast between the stops is observed the differences in intra-oral pressure are measured. Peak intra-oral pressure as measured over time, shows a difference between lenis and fortis stops. The measurement, termed the Pressure Impulse by Malécot (1966a, 1966b, 1970), calculates the integral of the function of peak oral pressure over time. The fortis stops have a higher pressure impulse than lenis stops. Geminates are similar in duration to fortis stops but have a pressure impulse that patterns between lenis and fortis stops.

A further hypothesis, which cannot be directly tested but can be inferred using these data was considered; the high pressure impulse measured within the closure of fortis stops may indicate some form of proprioceptive feedback effect. If there is a strong closure within the oral cavity—along with a closed velum—there is an associated sharp rise in intra-oral pressure. This will in turn require a greater closure force to maintain an occlusion. This effect was hypothesised by Malécot (1966b), although an exact measure of force of articulation remain elusive with very little cross-linguistic experimental evidence to support the characterisation (Debrock, 1977). Longer and more forceful

(tighter) closures have been shown in Italian geminates and singletons using electropalatography (Payne, 2006). This has also been shown in Tamil using static palatography (Ramasubramanian & Thosar, 1971). There is also a correlation between duration and degree of contact in Korean using dynamic electropalatography (Cho & Keating, 2001). This is now analysed as a prosodic effect however, by Fougeron and Keating (1997); Keating et al. (1998, 2004). In Biniŋ Gun-wok nasal and stop clusters it is the first—syllable final—element of the cluster showing a longer duration and this too may be a prosodic effect. This is not a prosodic analysis, however. Boundary strengthening may be particularly cogent when explaining the patterns found in Biniŋ Gun-wok and further research into this area may show that this occurs in the medial position (c.f. Baker, 2008).

Table 10.1 summarises the main acoustic phonetic differences between lenis and fortis stops. There are minimal acoustic differences between the stop categories apart from the aforementioned duration differences. Lenis and fortis stops are both unaspirated and can be described as having short-lag or coincident VOT (Lisker & Abramson, 1964). There is no significant difference in the preceding vowel duration.

TABLE 10.1: *Acoustical features of lenis and fortis stops in Biniŋ Gun-wok.*

MEASUREMENT	FORTIS	LENIS
Duration	long	short
Aspiration	Unaspirated	Unaspirated
VOT	+ ve	+ ve or -ve (not devoiced from previous segment)
VTT	devoiced	not devoiced
Preceding vowel duration	no difference	no difference
Amplitude of voice onset	no difference	no difference
Manner of voice onset	Abrupt	Abrupt if voicing has ceased during closure
Formant structure	no difference	no difference
Speech wave form	no obvious damping	no obvious damping
Allophonic articulation	rarely realised as approximant	frequently realised as approximant

There is debate within the linguistic literature as to whether there are any phonetic differences between single fortis stops and geminates. This study shows that in Bininj Gun-wok, geminates are phonetically distinct from fortis stops. The results summarised in Chapter 8 show that there are some acoustic and articulatory phonetic correlates that separate fortis stops from geminate clusters. These differences are summarised in Table 10.2. A potential phonetic cue to the difference is in the voice termination times (VTT) where the geminates show greater variation both within speakers and between speakers.

Differences in the pressure impulse between fortis stops and geminates suggest that there may be a less forceful oral occlusion in some geminates making them more phonetically akin to lenis stops from a closure perspective. Where they differ however is the longer duration. This results in a higher pressure impulse although the pressure rise is less rapid. A proportion of geminate tokens have pressure values (in terms of peak pressure) that are in the range shown by fortis stops but there is significant variability in this category just as there is in lenis stops. Further work is required to fully test this claim, however.

TABLE 10.2: *The differences between fortis, lenis stop categories and geminates in Bininj Gun-wok.*

MEASUREMENT	FORTIS	LENIS	GEMINATE
Overall duration (based on pressure and flow)	long	short	long
Voicing duration (VTT)	shorter	longer	longer
Voicing (VTT)	devoiced passively	voiced passively	voiced passively
Airflow at release	no difference	no difference	no difference
Air pressure before release	greater	smaller	medium (variable)
Pressure Impulse	high	low	medium (not variable)
Glottal setting (onset of C)	modal (weak abduction)	modal (weakly abducted)	modal (weakly abducted)
H1*-H2* at C onset	low (≈ 2)	low (≈ 2)	low (≈ 2)

The articulatory differences between lenis and fortis stops are mainly signalled by differences in intra-oral pressure values. To summarise the articula-

tory results, Table 10.2 shows the main contrast between the stop categories is in the pressure dimension rather than in the airflow. The contrast between the lenis and fortis categories based on duration and pressure over time can be combined into a single Pressure Impulse measurement. The main question that arises from these results is whether the higher pressure values are a direct result of the longer duration. Jaeger (1983) questioned whether duration and intra-oral pressure can be viewed as independent parameters and Butcher (1992) argues that due to the differences in pressure rise these parameters can be seen as separate. Butcher (2004) favours a rescaling hypothesis with fortis and lenis stops in a variety of Australian languages having different peak pressure targets. This study supports these findings and suggests that duration and pressure are independent in the medial position. The average time until the peak pressure within the stop is the same for both lenis and fortis stops yet the absolute value of peak pressure is generally lower for lenis stops supporting the rescaling hypothesis. Experiment 2 (Chapter 6), shows that the rise in pressure is greater during the closure for fortis stops supporting the results by Butcher (1992) for related languages. Whereas geminates tend to show peak pressures similar to lenis stops: pressures are maintained over a longer time period, and result in a greater pressure impulse for geminate clusters compared to lenis stops, but a lower pressure impulse when geminates are compared to fortis stops.

This study also shows that voicing is not independent of the closure duration and the force of the oral occlusion. The EGG data were correlated with the acoustic analysis to investigate laryngeal setting at the stop onset. This showed that there was an inverse correlation between the corrected measurement of spectral tilt ($H1^*-H2^*$) measured from the acoustic signal and the closed quotient measured using the EGG signal (Esposito, 2012, p. 474).¹

¹The * indicates that the measure was corrected for the effects of formant frequency and bandwidth as per Esposito (2012).

The results of the acoustic analysis of voicing profile shows that in the vowel preceding the medial stop there may be a very weak laryngeal abduction (opening) gesture but not one that suggests active devoicing in either of the stop types or in clusters. Fortis stops have a short voice termination time and a very weak glottal abduction gesture prior to oral closure. There is a suggestion from these data that there is a change in glottal state after the closure that may show that the glottis is adducted after the subglottal and supraglottal pressures have equalised—intra-oral pressure remains unchanged. This has yet to be demonstrated experimentally and consequently can only be regarded as an impressionistic result.

10.2 Coarticulation in nasals

Nasal articulation and the effects of nasals on the surrounding segments is reported in the third experiment. This measures the duration of nasals and stops in clusters. The central hypothesis tested concerns the tendency for the onset of nasalisation to be coincident or slightly delayed with respect to the oral closure when no preceding nasal is found within the word. Results show that carry-over nasalisation has a longer duration than anticipatory nasalisation in all single nasal and cluster environments involving nasals. As detailed above, carry-over nasalisation is not thought to be under direct muscular control, in contrast to anticipatory nasalisation.

One potential way in which carry-over nasalisation is able to be controlled is to produce a glottal stop word finally. In Bininj Gun-wok glottal stops are commonly found at the ends clusters of continuants but they are not found in combination with oral stops. This lends weight to the hypothesis that voicelessness is some form of boundary marker as proposed by Baker (2008) for Ngalakgan.

The clusters show interesting patterns. In a medial nasal + stop cluster

(N₁C₁) the nasal has a greater duration than the stop, but in a stop + nasal cluster (C₁N₁) the stop has the longer duration. In addition the stop shows many of the characteristics of a fortis articulation; a long duration—within the range of the single fortis stops reported in Chapter 5—with an associated high intra-oral pressure (P_o).

As with the medial oral stops, there is evidence from the clusters that the nasal or stop in coda position is strengthened in regard to both its duration but also the magnitude of nasal flow (U_n).

This suggests that these strengthening effects may be related to prosodic position. This has not been tested systematically with consonants in all prosodic positions, but it is well known that in Australian languages there are fewer phonological contrasts in an initial position and the post-tonic position has been found to be an important site of articulatory strengthening (Butcher, 2006a, forthcoming).

When pressure and flow are examined together, there is significant overlap in the production of a heterorganic cluster of a stop followed by a nasal. This coarticulation is to be expected, but voicing is delayed, however. In a homorganic cluster (CN) in contrast there is less overlap in the production of each segment.

10.3 Implications

The demonstration of differences between single fortis stops and geminate stop clusters is phonologically significant as this has only been verified quantitatively in a very few languages such as those listed in Lehiste et al. (1973, pp 133–7). The current study shows a difference between two oral stop categories—a single long stop, termed fortis and homorganic stop cluster, termed geminate—that are identical in terms of duration but differ in terms of voicing and intra-oral pressure. The pressure rise is indicative of greater force of articulation in

the fortis stops which way not be present in the geminates. Lenis stops have a lower duration, intra-oral pressure across the closure and are often realised as fully voiced stops, approximants or occasionally fricatives. They are very different in realisation to fortis stops which have an invariably long duration, high intra-oral pressure and a realised as voiceless stops with a relatively tight oral occlusion.

The stops that are classed lenis in Bininj Gun-wok are shorter in duration and the aerodynamic results point to less force used in maintaining the occlusion. There are however similar levels of respiratory force used for both lenis and fortis stops. The main difference is in the timing of the airflow peaks at the release. The lenis stops usually shows a delay in the airflow peak which can occur in the following vowel. When the airflow peak is delayed, the stop sounds voiced even when there is no voicing within the closure. This serves to greatly enhance the place of articulation cues and prolong the transition despite the closure being fully released. To investigate this further, perceptual experiments need to be conducted with first language speakers of Australian languages (see below).

The onset of nasalisation for medial nasals in Bininj Gun-wok also serves to enhance place of articulation cues. The formant transitions from vowel to nasal are very important carriers of place of articulation information and the presence of nasal anti-formants can erode these cues. In single nasals, the nasal peak far closer to the release than the onset of the oral closure which means that there is a carry-over of nasalisation into the following vowel. In clusters the same pattern occurs. When a stop directly precedes the nasal the stop is voiceless and providing the oral occlusion is tight, this serves to further delay the opening of the velum.

10.4 Limitations of the study

There are some factors that could not be controlled within the experimental design. Although the single lenis and fortis stops have been extensively examined in this study, the prohibitively high number of cluster combinations rules out an exhaustive examination of all possible alternatives. This complexity also prevented the systematic analysis of the links between fortis and glottal stops. A further limitation is that this study only uses of controlled speech. Although this is still not as controlled as many laboratory based experiments there are many connected speech processes that are not captured. Analysis of connected speech allows for more comprehensive prosodic and analysis of long-range coarticulatory effect. Many of the aspects of the language analysed here would not be possible in connected speech however as they are acoustically obscured or lost in fast, natural, speech.

The aerodynamic analysis showed that flow rates appear low by cross-language comparison (Baken & Orlikoff, 2000, citing Subtelny et al., 1966 and Lubker, 1973) and due to the low flow-rate in nasals particularly, is possible that the resistance in the flow-head in the analysis system was significant enough to affect the resulting measurements. The low flow-rate also made subsequent filtering challenging. Designing an experiment that elicited higher amplitude speech may have over-come this limitation. Leakage cannot be ruled out in all cases, as the masks sometimes slipped during recording. In the nasal recordings the oral mask did not always make a tight seal. As these recording were all conducted in the open air, there were a significant number that could not be analysed due to fluctuations in atmospheric pressure and changes in prevailing wind. Noisy recordings were discarded, but other more subtle changes in weather conditions such as the aforementioned pressure changes have affected the results.

Although there are relatively large quantities of previously recorded linguis-

tic data available for Bininj Gun-wok they can only be analysed quantitatively after careful labelling by a trained phonetician. Automatic segmentation methods, although maturing very quickly are not yet able to label with sufficient accuracy without extensive human correction. Additionally, only hierarchical databases similar to the Emu Speech Database used in this study are able to successfully combine both a segmental and a prosodic analysis as well as maintaining separate phonetic and phonological tiers. The hierarchy is essential for successful analysis of complex articulatory data as major landmarks may not be temporally congruent with the acoustic signal. The hierarchical querying tool was central to the quantitative analysis in this thesis as it enabled precise control over the position within the word of any segment measured. This study would not have been possible without such deep access to a database with this hierarchical structure.

10.5 Future work

This study presents a detailed analysis of medial stops in Bininj Gun-wok. Despite this, many medial stop realisations are not presented due to the large scale of such a study. The language is highly complex, with dialects that have distinct albeit related linguistic structures. The medial stop contrast and characteristics of nasal realisation found in this study are present in all of the dialects. Further research is needed to test whether similar patterns are found in other Australian languages as well as geographically related languages of Southern Asia.

Perception in Australian languages is a very important aspect of linguistic inquiry that still requires much further work. A perception experiment based around the knowledge of articulatory data, controlling for patterns of airflow and pressure may untangle the intricacies of inter-articulatory timing found in Bininj Gun-wok and give more insight into the voicing regularities observed in particular words across a variety of speakers. Although the stop contrasts

are not based on voicing there are regular differences that can be heard in the realisation of certain words related to consistent regulation of inter-articulator timing. This regularity is difficult to show experimentally relying on only production data alone.

Bininj Gun-wok is a vibrant language still actively spoken in daily life and acquired by children. Bininj Gun-wok has subsumed many of the surrounding languages ahead of Kriol² or English. Due to the small number of speakers however (< 2000) it is classified as an endangered language (Crystal, 2002).

There are many other languages in Australia and worldwide for which methodologies similar to the ones presented in this thesis may show similar results particularly in terms of aerodynamic timing where voice onset-time does not sufficiently differentiate between stop series. The morpho-syntactic structure of Bininj Gun-wok make it ideally suited to studies of this kind as it is possible to separate out place of articulation effects while keeping other phonetic factors as constant as possible.

In relation to unrecorded phonological contrasts in endangered languages Ladefoged and Everett (1996) say:

Only through the close investigation of endangered and less well known languages will we be able to gather data that will help distinguish the two types of features, those required for widespread phonological processes, and those that specify phonetic rarities (Ladefoged & Everett, 1996, p. 799).

This thesis adds to the literature regarding Bininj Gun-wok and Australian languages in general and prompts future work into the perception and production of medial stops. We are only just starting to understand the extent of the

²This covers a variety of English based creoles that usually structurally related to an Australian language with a vocabulary that is drawn from both an Australian language and English—see McConvell and Meakins (2005)

phonetic diversity amongst the languages of Australia and for many Australian languages—although it should be noted not all—it is too late for work of this scale. This time constraint makes this work all the more important. Identifying the similarities and differences between the phonetics Australian languages and English may further the opportunities for two-way cross-cultural collaboration into the future.

References

- Abberton, E. (1972). Some laryngographic data for Korean stops. *The Journal of the International Phonetic Association*, 2, 67-78.
- Abberton, E., & Fourcin, A. J. (1997). Electrolaryngography. In M. Ball & C. Code (Eds.), *Instrumental Clinical Phonetics*. London: Whurr.
- Abberton, E. R. M., Howard, D. M., & Fourcin, A. J. (1989). Laryngographic assessment of normal voice: a tutorial. *Clinical Linguistics Phonetics*, 3(3), 281-296. Retrieved from <http://informahealthcare.com/doi/abs/10.3109/02699208908985291> doi: 10.3109/02699208908985291
- Abramson, A., & Lisker, L. (1971, August 22-28). Voice timing in Korean stops. In A. Rigault & R. Charbonneau (Eds.), *Proceedings of the Seventh International Congress of Phonetic Sciences* (Vol. 439, p. 446).
- Abramson, A. S. (1977). Laryngeal timing in consonant distinctions. *Phonetica*, 34(4), 295-303.
- Abramson, A. S. (1986). The perception of word-initial consonant length: Pattani Malay. *Journal of the International Phonetic Association*, 16, 8-16.
- Abramson, A. S. (1987). Word-initial consonant length in Pattani Malay. In *International Congress of the Phonetic Sciences* (Vol. 6, pp. 68-70).
- Abramson, A. S. (1991). Amplitude as a cue to word-initial consonant length: Pattani Malay. In *Actes du XIIème Congrès International des Sciences Phonétiques* (Vol. 3, pp. 98-101). Aix-en-Provence, France.
- Abramson, A. S. (2003). Acoustic cues to word-initial stop length in Pattani

- Malay. In *Proc. 15th Int. Congr. Phonet. Sciences* (pp. 387–390). Barcelona, Spain.
- Allen, G., Midgley, S., & Allen, M. (2002). *Field guide to the freshwater fishes of Australia*. Perth: Western Australian Museum.
- Anderson, V. B. (2000). *Giving Weight to Phonetic Principles: The Case of Place of Articulation in Western Arrernte* (PhD Thesis). University of California.
- Anderson, V. B., & Maddieson, I. (1994). Acoustic characteristics of Tiwi coronal stops. *UCLA Working Papers in Phonetics*, 87, 131-162.
- Anthony, J., & Hewlett, N. (1997). Aerometry. In M. Ball & C. Code (Eds.), *Instrumental Clinical Phonetics*. London: Whurr.
- Aoyama, K., & Reid, L. A. (2006). Cross-linguistic tendencies and durational contrasts in geminate consonants: an examination of Guinaang Bontok geminates. *Journal of the International Phonetic Association*, 36(02), 145-157. Retrieved from <http://dx.doi.org/10.1017/S0025100306002520> doi: 10.1017/S0025100306002520
- Applegate, J. (1958). *An outline of the structure of Shilha*. New York: American Council of Learned Societies.
- Aronoff, M. (1976). *Word Formation in Generative Grammar*. Cambridge, Mass.: MIT Press.
- Arvaniti, A. (1999). Cypriot Greek. *Journal of the International Phonetic Association*, 29(02), 173–178.
- Arvaniti, A., & Tserdanelis, G. (2000). On the phonetics of geminates: evidence from Cypriot Greek. In *6th International Conference on Spoken Language Processing* (Vol. 2, p. 559-562). Beijing, China.
- Austin, P. (1988). Phonological voicing contrasts in Australian Aboriginal languages. *LaTrobe Working Papers in Linguistics*, 1(17-42).
- Baayen, R. (2008). *Analyzing linguistic data: A practical introduction to statistics*. Cambridge, Eng.: Cambridge University Press.
- Baayen, R., Davidson, D., & Bates, D. (2008). Mixed-effects modeling with

- crossed random effects for subjects and items. *Journal of Memory and Language*, 59(4), 390–412.
- Baayen, R. H. (2011). languageR: data sets and functions with “Analyzing linguistic data: A practical introduction to statistics”. [Computer software manual]. Retrieved from <http://CRAN.R-project.org/package=languageR> (R package version 1.4)
- Baken, R., & Orlikoff, R. (2000). *Clinical Measurement of Speech and Voice* (2nd ed.). Singular Publishing Group.
- Baken, R. J. (1992). Electrolottography. *Journal of Voice*, 6(2), 98 - 110. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0892199705801237> doi: 10.1016/S0892-1997(05)80123-7
- Baker, B. J. (1999). *Word Structure in Ngalakgan* (PhD Thesis). The University of Sydney.
- Baker, B. J. (2004). Review of “Bininj Gun-Wok (2 volumes)”. *Oceania*, 75(2), 153-154.
- Baker, B. J. (2008). *Word Structure in Ngalakgan*. Stanford, California: Centre for the Study of Language and Information.
- Balasubramanian, T. (1972). *The Phonetics of Colloquial Tamil* (PhD Thesis). University of Edinburgh.
- Basset, P., Amelot, A., Vaissière, J., & Roubeau, B. (2002). Nasal airflow in French spontaneous speech. *Journal of the International Phonetic Association*, 31(01), 87-99.
- Bates, D. (2005). Fitting linear mixed models in R. *R news*, 5(1), 27–30.
- Bates, D., Maechler, M., & Bolker, B. (2011). lme4: Linear mixed-effects models using S4 classes [Computer software manual]. Retrieved from <http://CRAN.R-project.org/package=lme4> (R package version 0.999375-42)
- Beckman, M., Edwards, J., & Fletcher, J. (1992). Prosodic structure and tempo

- in a sonority model of articulatory dynamics. *Papers in Laboratory Phonology II*, 68–86.
- Bell-Berti, F. (1976). An electromyographic study of velopharyngeal function in speech. *Journal of Speech and Hearing Research*, 19(2), 225-240. Retrieved from <http://jslhr.asha.org/cgi/content/abstract/19/2/225>
- Bell-Berti, F. (1993). Understanding velic motor control: studies of segmental context. In M. K. Huffman & R. A. Krakow (Eds.), *Nasals, Nasalization and the Velum* (Vol. 5, pp. 63–85). San Diego: Academic Press.
- Bell-Berti, F., & Harris, K. S. (1981). A temporal model of speech production. *Phonetica*, 38(1-3), 9-20.
- Bell-Berti, F., Krakow, R., Gelfer, C., & Boyce, S. (1995). Anticipatory and carryover effects: Implications for models of speech production. In F. Bell-Berti & L. J. Raphael (Eds.), *Producing Speech: Contemporary Issues. For Katherine Safford Harris*. New York, NY: AIP.
- Bell-Berti, F., & Krakow, R. A. (1991). Anticipatory velar lowering: a coproduction account. *The Journal of the Acoustical Society of America*, 90(1), 112-123.
- Bell-Berti, F., Krakow, R. A., & Ross, D. (1993). Velar coarticulation revisited (A). *The Journal of the Acoustical Society of America*, 94(3), 1881-1881.
- Beranek, L. L. (1996). *Acoustics*. Woodbury, New York: The Acoustical Society of America.
- Berndt, C. H. (1951). Some figures of speech and oblique references in an Australian language (Gunwinggu). *Southwestern Journal of Anthropology*, 7(3), 266-271.
- Berndt, C. H., & Berndt, R. M. (1951). An Oenpelli monologue: culture contact. *Oceania*, 22, 24.
- Berndt, R. M. (1951). Ceremonial Exchange in Western Arnhem Land. *Southwestern Journal of Anthropology*, 7(2), 156-176.

- Berndt, R. M., & Berndt, C. H. (1970). *Man, Land and Myth in North Australia: The Gunwinggu People*. East Lansing: Michigan State University Press.
- Bishop, J. (2002a). *Aspects of Intonation and Prosody in Bininj-Gun-Wok: An Autosegmental Metrical Analysis* (Unpublished doctoral dissertation). The University of Melbourne.
- Bishop, J. (2002b). 'Stress accent' without phonetic stress: Accent type and distribution in Bininj Gun-Wok. In *Speech Prosody*. Aix-en-Provence, France.
- Bishop, J., & Fletcher, J. (2005). Intonation in six dialects of Bininj Gun-Wok. In S.-A. Jun (Ed.), *Prosody and typology - a unified approach*. Oxford: Oxford University Press.
- Bladon, R. A., & Al-Bamerni, A. (1982). One stage and two-stage temporal patterns of velar coarticulation (A). *The Journal of the Acoustical Society of America*, 72, S104.
- Bladon, R. A. W., & Al-Bamerni, A. (1976). Coarticulation resistance in English /l/. *Journal of Phonetics*, 4(2), 137–150.
- Blevins, J. (2004). *Evolutionary Phonology: the Emergence of Sound Patterns*. Cambridge, UK: Cambridge University Press.
- Boersma, P., & Weenink, D. (2013). *Praat: Doing Phonetics by Computer [Computer Program]*. The University of Amsterdam. (retrieved: 08/12/2013 from <http://www.praat.org>, Version: 5.3.60)
- Bombien, L., Cassidy, S., Harrington, J., John, T., & Palethorpe, S. (2006). Recent developments in the Emu Speech Database System. In *Proceedings of the 11th Speech Science and Technology Conference Auckland* (pp. 313–316).
- Bouhuys, A., Mead, J., Proctor, D. F., & Stevens, K. N. (1968). Pressure-flow events during singing. *Annals of the New York Academy of Sciences*, 155(1), 165-176.
- Bowern, C., McDonough, J., & Kelliher, K. (2012, 12). Bardi. *Journal of the International Phonetic Association*, 42, 333–351. Retrieved from

- http://journals.cambridge.org.ezp.lib.unimelb.edu.au/article_S0025100312000217 doi: 10.1017/S0025100312000217
- Bradley, D. (1980). Acoustic correlates of seven consonant positions in Yanyuwa. *Working Papers in Linguistics*, 6, 21–48.
- Brancazio, L., & Fowler, C. A. (1998). On the relevance of locus equations for production and perception of stop consonants. *Perception & psychophysics*, 60(1), 24–50.
- Breen, G., & Dobson, V. (2005). Central Arrernte. *Journal of the International Phonetic Association*, 35(02), 249–254.
- Breen, G., & Pensalfini, R. (1999). Arrernte: a language with no syllable onsets. *Linguistic Inquiry*, 30(1), pp. 1–25. Retrieved from <http://www.jstor.org/stable/4179048>
- Browman, C. P., & Goldstein, L. (1990a). Gestural specification using dynamically-defined articulatory structures. *Journal of Phonetics*, 18(3), 299–320.
- Browman, C. P., & Goldstein, L. (1992). Articulatory phonology: an overview. *Phonetica*, 49(3–4), 155–180.
- Browman, C. P., & Goldstein, M., Louis. (1990b). Representation and reality: physical systems and phonological structures. *Journal of Phonetics*, 18(3), 411–24.
- Browman, C. P., & Goldstein, M., Louis. (1990c). Tiers in articulatory phonology, with some implications for casual speech. In T. Kingston & M. E. Beckman (Eds.), *Papers in laboratory phonology I: Between the grammar and physics of speech* (pp. 341–76). Cambridge: Cambridge University Press.
- Bundgaard-Nielsen, R. L., Baker, B. J., Harvey, M., Best, C. T., & Kroos, C. (2012). The perception of coronal stops in Wubuy. In *Proceedings of the 14th Speech Science and Technology Conference*. Sydney, Australia.
- Busby, P. (1980). The distribution of phonemes in Australian Aboriginal languages. *Papers in Australian Linguistics*, 4, 73–139.

- Butcher, A. R. (1977). Coarticulation in intervocalic voiceless plosives and fricatives in connected speech. *Arbeitsberichte des Instituts für Phonetik der Universität Kiel*, 8, 154-212.
- Butcher, A. R. (1992). Intraoral pressure as an independent parameter in oral stop contrasts. In J. Pittam (Ed.), *4th Australian international conference on speech science and technology*. (p. 286-291). Canberra: Australian Speech Science and Technology Association.
- Butcher, A. R. (1994). On the phonetics of small vowel systems: evidence from Australian languages. In R. Togneri (Ed.), *5th Australian international conference on speech science and technology* (Vol. 1, p. 28-33). Canberra: Australian Speech Science and Technology Association,.
- Butcher, A. R. (1995). The phonetics of neutralisation: the case of Australian coronals. In J. Windsor Lewis (Ed.), *Studies in General and English Phonetics: Essays in honour of Professor J.D. O'Connor* (p. 10-38). London: Routledge.
- Butcher, A. R. (1996). Some connected speech phenomena in Australian languages: universals and idiosyncrasies. In A. P. Simpson & M. Pätzold (Eds.), *Sound Patterns of Connected Speech: Description, Models and Explanation*. (p. 83-104). Kiel University: Institut für Phonetikder Universität Kiel.
- Butcher, A. R. (1999). What speakers of Australian Aboriginal languages do with their velums and why: The phonetics of the nasal/oral contrast. In *XIVth International Conference of Phonetic Science*. San Francisco.
- Butcher, A. R. (2004). 'Fortis/lenis' revisited one more time: the aerodynamics of some oral stop contrasts in three continents. *Clinical Linguistics & Phonetics*, 18, 547-557.
- Butcher, A. R. (2006a). Consonant-salient phonologies and the 'place-of-articulation imperative'. In J. Harrington & M. Tabain (Eds.), *Speech Production: Models, Phonetic Processes and Techniques* (pp. 187-210). New York: Psychology Press.

- Butcher, A. R. (2006b). *Three kinds of stop contrast in Northern Australian Languages*. (to be included in Butcher (forthcoming) *The Phonetics of Australian Languages*, Oxford)
- Butcher, A. R. (2008). Linguistic aspects of Australian Aboriginal English. *Clinical Linguistics & Phonetics*, 22(8), 625-642. Retrieved from <http://informahealthcare.com/doi/abs/10.1080/02699200802223535> doi: 10.1080/02699200802223535
- Butcher, A. R. (forthcoming). *The Phonetics of Australian Languages (m.s.)*. Oxford: Oxford University Press.
- Butcher, A. R., & Harrington, J. (2003a). An acoustic and articulatory analysis of focus and the word/morpheme boundary distinction in Warlpiri. In *6th International Seminar on Speech Production*. Sydney.
- Butcher, A. R., & Harrington, J. (2003b). An instrumental analysis of focus and juncture in Warlpiri. In *15th International Conference of Phonetic Science*. Barcelona.
- Butcher, A. R., & Loakes, D. E. (2008). Enhancing the left edge: The phonetics of prestopped sonorants in Australian languages. *The Journal of the Acoustical Society of America*, 124(4), 2527-2527. Retrieved from <http://link.aip.org/link/?JAS/124/2527/1>
- Butcher, A. R., & Tabain, M. (2004). On the back of the tongue: Dorsal sounds in Australian languages. *Phonetica*, 61, 22-52.
- Byrd, D. (1993). 54,000 American stops. *UCLA Working Papers in Phonetics*, 83, 97-116.
- Byrd, D., & Saltzman, E. (2003). The elastic phrase: modeling the dynamics of boundary-adjacent lengthening. *Journal of Phonetics*, 31(2), 149-180.
- Capell, A. (1942). Languages of Arnhem Land, North Australia. *Oceania*, 12, 364-92.
- Capell, A. (1962). *Dalabon Grammar, (Handbook of Australian Languages, Part 2) (No. 7)*. Oceania Linguistics.

- Capell, A. (1967). Sound systems in Australia. *Phonetica*, 16(2), 85–110.
- Carroll, P. (1976). *Kunwinjku (Gunwinggu): A language of Western Arnhem Land* (Masters Thesis). Australian National University, Canberra.
- Cassidy, S., & Harrington, J. (2001). Multi-level annotation in the Emu speech database management system. *Speech Communication*, 33(1-2), 61-77.
- Catford, J. (1977). *Fundamental problems in phonetics*. Edinburgh University Press Edinburgh.
- Catford, J. C. (1988). *A Practical Introduction to Phonetics*. Oxford University Press New York.
- Chafcouloff, M., & Marchal, A. (1999). Velopharyngeal coarticulation. In W. J. Hardcastle & N. Hewlett (Eds.), *Coarticulation: Theory, data and techniques* (pp. 69–79). Cambridge University Press.
- Cho, T., & Jun, S.-A. (2000). Domain initial strengthening as enhancement of laryngeal features: Aerodynamic evidence from Korean. *Working Papers in Phonetics*, 99, 57-69.
- Cho, T., Jun, S.-A., & Ladefoged, P. (2002). Acoustic and aerodynamic correlates of Korean stops and fricatives. *Journal of Phonetics*, 30, 193-228.
- Cho, T., & Keating, P. (2001). Articulatory and acoustic studies on domain-initial strengthening in Korean. *Journal of Phonetics*, 29(2), 155-190.
- Cho, T., & Ladefoged, P. (1999). Variation and universals in VOT: evidence from 18 languages. *Journal of Phonetics*, 27(2), 207–229.
- Chomsky, N., & Halle, M. (1968). *The Sound Pattern of English*. New York, NY: Harper and Row.
- Clark, H. (1973). The language-as-fixed-effect fallacy: A critique of language statistics in psychological research. *Journal of verbal learning and verbal behavior*, 12(4), 335–359.
- Clements, N. G., & Keyser, S. (1983). *CV Phonology. A Generative Theory of the Syllable*. Cambridge, Mass.: The MIT Press.
- Clumeck, H. (1976). Patterns of soft palate movements in six languages. *Journal*

- of Phonetics*, 4(4), 337–351.
- Cohn, A. C. (1990). *Phonetic and Phonological Rules of Nasalization* (Unpublished doctoral dissertation). UCLA.
- Cohn, A. C., Ham, W. H., & Podesva, R. J. (1999). The phonetic realization of singleton-geminate contrasts in three languages of Indonesia. In *14th International Conference of Phonetic Science*. San Francisco.
- Cohn, A. C., & Riehl, A. K. (2008). The internal structure of nasal-stop sequences: evidence from Austronesian. *Working Papers of the Cornell Phonetics Laboratory*.
- Crystal, D. (2002). *Language Death*. Cambridge, Eng.: Cambridge University Press.
- Dart, S. N. (1984). Testing an aerodynamic model with measured data from Korean. *Phonetics, Working Papers, UC Los Angeles: Department of Linguistics, UCLA., WPP, No. 59*, 1–17.
- Dart, S. N. (1987). An aerodynamic study of Korean stop consonants: Measurements and modeling. *The Journal of the Acoustical Society of America*, 81(1), 138–147.
- Dart, S. N., & Nihalani, P. (1999). The articulation of Malayalam coronal stops and nasals. *Journal of the International Phonetic Association*, 29(02), 129–142. Retrieved from <http://dx.doi.org/10.1017/S0025100300006502> doi: 10.1017/S0025100300006502
- Debrock, M. (1977). An acoustic correlate of the force of articulation. *Journal of Phonetics*, 5, 61–80.
- Delattre, P. C. (1971a). Consonant gemination in four languages: An acoustic, perceptual, and radiographic study, Part I. *International Review of Applied Linguistics in Language Teaching*, 9(2), 31–52.
- Delattre, P. C. (1971b). Consonant gemination in four languages: An acoustic, perceptual, and radiographic study, Part II. *International Review of Applied Linguistics in Language Teaching*, 9(2), 97–114.

- Delattre, P. C., Berman, A., & Cooper, F. S. (1962). Formant transitions and loci as acoustic correlates of place of articulation in American fricatives. *Studia linguistica*, 16(1-2), 104-122.
- Delattre, P. C., Liberman, A. M., & Cooper, F. S. (1955). Acoustic loci and transitional cues for consonants. *The Journal of the Acoustical Society of America*, 27, 769.
- Delvaux, V., Demolin, D., Harmegnies, B., & Soquet, A. (2008). The aerodynamics of nasalization in French. *Journal of Phonetics*, 36(4), 578-606.
- DiCanio, C. T. (2008). *The Phonetics and Phonology of San Martín Itunyoso Trique* (PhD Thesis). The University of California, Berkeley.
- DiCanio, C. T. (2009). The phonetics of register in Takhian Thong Chong. *Journal of the International Phonetic Association*, 39(02), 162-188.
- DiCanio, C. T. (2010). Itunyoso Trique. *Journal of the International Phonetic Association*, 40(02), 227-238. Retrieved from <http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=7832922&fulltextType=RA&fileId=S0025100310000034> doi: 10.1017/S0025100310000034
- DiCanio, C. T. (2012). The phonetics of fortis and lenis consonants in Itunyoso Trique. *International Journal of American Linguistics*, 78(2), 239-272.
- Disner, S. F. (1984). Insights on vowel spacing. In I. Maddieson & S. F. Disner (Eds.), *Patterns of Sounds*. Cambridge: Cambridge University Press.
- Dixit, R. P., & MacNeilage, P. F. (1972). Coarticulation of nasality: Evidence from Hindi (A). *The Journal of the Acoustical Society of America*, 52(1A), 131-132. Retrieved from <http://link.aip.org/link/?JAS/52/131/5> doi: 10.1121/1.1981846
- Dixon, R. M. W. (1980). *The Languages of Australia*. Cambridge, Eng. ; New York: Cambridge University Press.
- Dixon, R. M. W. (2002). *Australian Languages: Their Nature and Development*. Cambridge, UK: Cambridge University Press.

- Docherty, G. J. (1992). *The timing of voicing in British English obstruents*. Berlin: Foris Publications.
- Dorman, M. F., Studdert-Kennedy, M., & Raphael, L. J. (1977). Stop-consonant recognition: Release bursts and formant transitions as functionally equivalent, context-dependent cues. *Perception & Psychophysics*, 22(2), 109-122.
- Doty, C. S., Idemaru, K., & Guion, S. G. (2007). Singleton and geminate stops in Finnish – acoustic correlates. In *The Proceedings of the 8th Annual Conference of the International Speech Communication Association* (pp. 2737–2740).
- Edwards, J., Beckman, M. E., & Fletcher, J. (1991). The articulatory kinematics of final lengthening. *The Journal of the Acoustical Society of America*, 89(1), 369-382. Retrieved from <http://link.aip.org/link/?JAS/89/369/1> doi: 10.1121/1.400674
- Esposito, C. M. (2010). Variation in contrastive phonation in Santa Ana Del Valle Zapotec. *Journal of the International Phonetic Association*, 40(02), 181-198. Retrieved from <http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=7832925&fulltextType=RA&fileId=S0025100310000046> doi: 10.1017/S0025100310000046
- Esposito, C. M. (2012). An acoustic and electroglottographic study of White Hmong tone and phonation. *Journal of Phonetics*, 40(3), 466 - 476. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0095447012000174> doi: 10.1016/j.wocn.2012.02.007
- Etherington, S. (2006). *Learning to be Kunwinjku: Kunwinjku people discuss their pedagogy* (PhD Thesis). Faculty of Health, Education and Science, Charles Darwin University.
- Etherington, S., & Etherington, N. (1998). *Kunwinjku Kunwok: A short introduction to Kunwinjku language and society* (3rd ed.). Kunbarllanjnja: The

- Kunwinjku Language Centre.
- Evans, B., & Merlan, F. (2004). Stop contrasts in languages of Arnhem land: From the perspective of Jawoyn, Southern Arnhem land. *Australian Journal of Linguistics*, 24(2), 185-224.
- Evans, N. (1989). *How to write Gun-djeyhmi* (Manuscript). Australian Parks and Wildlife Service and the Gagudju Association.
- Evans, N. (1995). Current issues in the phonology of Australian languages. In J. A. Goldsmith (Ed.), *Handbook of Phonological Theory*. Cambridge, Mass: Blackwells.
- Evans, N. (1997). Head classes and agreement classes in the Mayali dialect chain. In M. Harvey & N. Reid (Eds.), *Nominal classification in Aboriginal Australia* (Vol. 37, pp. 105–46). John Benjamins Publishing Co.
- Evans, N. (2003). *Bininj Gun-Wok: a pan-dialectal grammar of Mayali, Kunwinjku and Kune* (No. 541). Canberra: Pacific Linguistics, Research School of Pacific and Asian Studies, Australian National University.
- Evans, N. (2004). Bininj Gun-Wok. In P. J. L. Arnaud (Ed.), *Le nom composé: données sur seize langues* (p. 71-99). Presses Universitaires de Lyon.
- Evans, N. (2010). *Dying words: Endangered languages and what they have to tell us*. Wiley-Blackwell.
- Farnetani, E., & Kori, S. (1986). Effects of syllable and word structure on segmental durations in spoken Italian. *Speech communication*, 5(1), 17–34.
- Farnetani, E., & Recasens, D. (1999). Coarticulation models in recent speech production theories. In W. J. Hardcastle & N. Hewlett (Eds.), *Coarticulation: theory, data and techniques* (pp. 31–65). Cambridge University Press.
- Farnetani, E., & Recasens, D. (2013). Coarticulation and connected speech processes. In W. J. Hardcastle, J. Laver, & F. E. Gibbon (Eds.), *The Handbook of Phonetic Sciences* (Vol. 79). Chichester, U.K.: Wiley-Blackwell.
- Fischer-Jørgensen, E. (1954). Acoustic analysis of stop consonants. *Miscellanea*

- Phonetica*, 2(1), 42-59.
- Fischer-Jørgensen, E. (1968). Voicing, tenseness and aspiration in stop consonants, with special reference to French and Danish. *Annual Report of the Institute of Phonetics, University of Copenhagen*, 3, 63–114.
- Flege, J. E. (1988). Anticipatory and carry-over nasal coarticulation in the speech of children and adults. *Journal of Speech and Hearing Research*, 31(4), 525-536. Retrieved from <http://jslhr.asha.org/cgi/content/abstract/31/4/525>
- Fletcher, J., Butcher, A., Loakes, D., & Stoakes, H. (2010). Aspects of nasal realization and the place of articulation imperative in Biniŋ Gun-wok. In *Proceedings of the 13th Speech Science and Technology Conference*. Melbourne.
- Fletcher, J., & Butcher, A. R. (2002). Vowel dispersion in two Northern Australian languages: Dalabon and Biniŋ Gun-Wok. In C. Bow (Ed.), *9th Australian International Conference on Speech Science and Technology* (p. 343-348). Melbourne: Australian Speech Science and Technology Association Inc.
- Fletcher, J., & Butcher, A. R. (2003). Local and global Influences on vowel formants in three Australian languages. In *15th International Conference of Phonetic Science*. Barcelona, Spain: UAB.
- Fletcher, J., & Evans, N. (2000). Intonational downtrends in Mayali. *Australian Journal of Linguistics*, 20(1), 23-38.
- Fletcher, J., & Evans, N. (2002). An acoustic phonetic analysis of intonational prominence in two Australian languages. *Journal of the International Phonetic Association*, 32(02), 123-140.
- Fletcher, J., Loakes, D., & Butcher, A. (2009). Coarticulation in nasal and lateral clusters in Warlpiri. In *Annual conference- international speech communication association* (1st ed., Vol. 1, pp. 86–89). Retrieved from <https://ezp.lib.unimelb.edu.au/login?url=https://>

search.ebscohost.com/login.aspx?direct=true&db=edsbl&AN=CN079803477&site=eds-live

- Fletcher, J., Stoakes, H. M., Loakes, D., & Butcher, A. R. (2007). Spectral and durational properties of vowels in Kunwinjku. In *16th International Congress of the Phonetic Sciences*. Saarbrücken.
- Fletcher, J. M., Butcher, A. R., Loakes, D., & Stoakes, H. (2011). Coarticulation and consonant cluster production in Iwaidja. *The Journal of the Acoustical Society of America*, 129(4), 2452-2452. Retrieved from <http://link.aip.org/link/?JAS/129/2452/2> doi: 10.1121/1.3588048
- Fletcher, S. G., Sooudi, I., & Frost, S. D. (1974). Quantitative and graphic analysis of prosthetic treatment for “nasalance” in speech. *The Journal of Prosthetic Dentistry*, 32(3), 284 - 291. Retrieved from <http://www.sciencedirect.com/science/article/pii/0022391374900328> doi: [http://dx.doi.org/10.1016/0022-3913\(74\)90032-8](http://dx.doi.org/10.1016/0022-3913(74)90032-8)
- Fougeron, C., & Keating, P. A. (1997). Articulatory strengthening at edges of prosodic domains. *The Journal of the Acoustical Society of America*, 101(6), 3728-3740. Retrieved from <http://link.aip.org/link/?JAS/101/3728/1> doi: 10.1121/1.418332
- Fowler, C., & Saltzman, E. (1993). Coordination and coarticulation in speech production. *Language and speech*, 36(2-3), 171-195.
- Fowler, C. A. (1994). Invariants, specifiers, cues: An investigation of locus equations as information for place of articulation. *Perception & Psychophysics*, 55(6), 597-610.
- Fraser, H. (n.d.). *Phonetics of Tamil: Double Stops*. (Oxford)
- Garde, M. (2002). *Social deixis in Bininj Kun-wok conversation* (PhD Thesis). The University of Queensland.
- Garde, M. (2008a). Kun-dangwok: clan lects and Ausbau in western Arnhem Land. *International Journal of the Sociology of Language*, 191, 141-169.

- Garde, M. (2008b). Person reference, proper names and circumspection in Bininj Kunwok conversation. In I. Mushin & B. Baker (Eds.), *Discourse and Grammar in Australian Languages* (Vol. 104). Amsterdam: John Benjamins Publishing Co.
- Garde, M. (2011). *Bininj Gunwok: Talk About Health, Medical terms and Vocabulary for Health Professionals*. Jabiru: Gundjeihmi Aboriginal Corporation.
- Garde, M. (in press). *Kuninjku Dictionary*. ANU.
- Garellek, M., Keating, P., Esposito, C. M., & Kreiman, J. (2013). Voice quality and tone identification in White Hmong. *The Journal of the Acoustical Society of America*, 133(2), 1078-1089. Retrieved from <http://link.aip.org/link/?JAS/133/1078/1> doi: 10.1121/1.4773259
- Gauster, A., Yunusova, Y., & Zajac, D. (2010). The effect of speaking rate on velopharyngeal function in healthy speakers. *Clinical Linguistics Phonetics*, 24(7), 576 - 588. Retrieved from <https://ezp.lib.unimelb.edu.au/login?url=https://search-ebshost-com.ezp.lib.unimelb.edu.au/login.aspx?direct=true&db=ufh&AN=51528562&site=eds-live>
- Gick, B., Wilson, I., & Derrick, D. (2012). *Articulatory Phonetics*. Chichester, U.K.: John Wiley & Sons.
- Graetzer, S. (2007). Consonantal coarticulation resistance in vowel-consonant-vowel sequences. In *Proceedings of the 16th International Congress of Phonetics Sciences*.
- Graetzer, S. (2012). *An Acoustic Study of Coarticulation: Consonant-Vowel and Vowel-to-Vowel Coarticulation in Four Australian Languages* (PhD Thesis). School of Languages and Linguistics, The University of Melbourne.
- Green, I. (1989). *Marrithiyel: A Language of the Daly River Region of Australia's Northern Territory* (PhD Thesis). Australian National University,, Canberra.
- Green, R. (1987). *A Sketch Grammar of Burarra* (Unpublished doctoral disser-

- tation). Australian National University.
- Hale, K. (1976). Phonological developments in particular Northern Paman languages. In P. Sutton (Ed.), *Languages of Cape York* (pp. 41–49). Canberra: Australian Institute of Aboriginal Studies.
- Ham, W. H. (1998). *Phonetic and phonological aspects of geminate timing* (Unpublished doctoral dissertation). Cornell.
- Hamilton, P. J. (1996). *Phonetic Constraints and Markedness in the Phonotactics of Australian Aboriginal Languages* (PhD Thesis). University of Toronto.
- Hamzah, H. (2013). *Word initial Geminate in Kelantan Malay* (Unpublished doctoral dissertation). The School of Languages and Linguistics, The University of Melbourne.
- Hamzah, H., Fletcher, J., & Hajek, J. (2011). Durational correlates of word-initial voiceless geminate stops: the case of Kelantan Malay. *Proc. ICPhS XVII*, 89–92.
- Hamzah, H., Fletcher, J., & Hajek, J. (2012). An Acoustic Analysis of Release Burst Amplitude in the Kelantan Malay Singleton/Geminate Stop Contrast. In F. Cox, K. Demuth, S. Lin, K. Miles, & S. Palethorpe (Eds.), *Proceedings of the 14th Conference on Speech Science and Technology* (pp. 85–88).
- Hamzah, H., Hajek, J., & Fletcher, J. (2012). A taste of prosody: Possible effects of the word-initial singleton-geminate contrast on post-consonantal vowel duration in Kelantan Malay. *Proc. 6th Speech Prosody*.
- Han, M., & Weitzman. (1970). Acoustic features of Korean /P, T, K/, /p, t, k/ and /ph, th, kh/. *Phonetica*, 22(2), 112–123.
- Hansen, B. B. (2004). Production of Persian geminate stops: Effects of varying speaking rate. *Proceedings of the 2003 Texas Linguistics Society Conference*, ed, 86–95.
- Hardcastle, W. J. (1973). Some observations on the tense-lax distinction in initial stops in Korean. *Journal of Phonetics*, 1, 263–271.
- Harrington, J. (2010). *The Phonetic Analysis of Speech Corpora*. Chichester,

- U.K.: Wiley-Blackwell.
- Harrington, J. (2012). Acoustic phonetics. In W. J. Hardcastle, J. Laver, & F. E. Gibbon (Eds.), *The Handbook of Phonetic Sciences* (2nd ed., Vol. 79, p. 81). Chichester, U.K.: Wiley-Blackwell.
- Harrington, J., & Cassidy, S. (2000). Techniques in speech acoustics. *Computational Linguistics*, 26(2), 294–295.
- Harrington, J., Cassidy, S., Fletcher, J., & McVeigh, A. (1993). The mu+ system for corpus based speech research. *Computer, Speech and Language*, 7, 305–331.
- Harrington, J., Cassidy, S., John, T., & Scheffers, M. (2003). Building an interface between EMU and Praat: a modular approach to speech database analysis. In *Proceedings of the 15th International Congress of the Phonetic Sciences*. Barcelona, Spain.
- Harrington, J., Fletcher, J., & Roberts, C. (1995). Coarticulation and the accented/unaccented distinction: evidence from jaw movement data. *Journal of Phonetics*, 23(3), 305–322.
- Harrington, J., John, T., others, Kiel, IPS, & LMU Muenchen IPDS. (2012). emu: Interface to the emu speech database system [Computer software manual]. Retrieved from <http://CRAN.R-project.org/package=emu> (R package version 4.3)
- Harris, J. K. (1969). *Descriptive and Comparative Study of the gUnwingguan Languages, Northern Territory* (PhD Thesis). Australian National University.
- Harvey, M. (1991). Glottal stop, underspecification, and syllable structures among the top end languages. *Australian Journal of Linguistics*, 11(1), 67 – 105.
- Harvey, M. (2002). *A Grammar of Gaagudju* (No. 24). Berlin ; New York: Mouton de Gruyter.
- Heath, J. (1980a). *Basic materials in Ritharngu: Grammar, texts and dictionary*. (Vol. B-62). Canberra: Pacific Linguistics.

- Heath, J. (1980b). *Dhuwal (Arnhem Land) texts on kinship and other subjects with grammatical sketch and dictionary* (No. 23). Sydney, Australia: Oceania Linguistic Monographs.
- Herbst, C., & Ternström, S. (2006). A comparison of different methods to measure the EGG contact quotient. *Logopedics Phoniatrics Vocology*, 31(3), 126-138.
- Hercus, L. A. (1972). The pre-stopped nasal and lateral consonants of Arabana-Wanjanuru. *Anthropological Linguistics*, 14(8), pp. 293-305. Retrieved from <http://www.jstor.org/stable/30029330>
- Hirose, H., Lee, C., & Ushijima, T. (1974). Laryngeal control in Korean stop production. *Journal of Phonetics*, 2-145.
- Hirose, H., Yoshioka, H., & Niimi, S. (1979). A cross language study of laryngeal adjustment in consonant production. In *Current issues in the phonetic sciences: Proceedings of the IPS-77 congress, Miami Beach Florida* (p. 165-179).
- Hoddinott, W. G., & Kofod, F. M. (1988). *The Ngankikurungkurr Language (Daly River Area, Northern Territory)* [Book]. Canberra: Dept. of Linguistics, Research School of Pacific Studies Australian National University.
- Holmberg, E. B., Hillman, R. E., & Perkell, J. S. (1988). Glottal airflow and transglottal air pressure measurements for male and female speakers in soft, normal, and loud voice. *The Journal of the Acoustical Society of America*, 84(2), 511-529. Retrieved from <http://link.aip.org/link/?JAS/84/511/1> doi: 10.1121/1.396829
- Howard, D., Lindsey, G., & Allen, B. (1990). Toward the quantification of vocal efficiency. *Journal of Voice*, 4(3), 205-212.
- Howard, D. M. (1995). Variation of electrolaryngographically derived closed quotient for trained and untrained adult female singers. *Journal of Voice*, 9(2), 163-172.
- Huffman, M. K. (1987). Measures of phonation type in Hmong. *The Journal of*

- the Acoustical Society of America*, 81(2), 495-504. Retrieved from <http://link.aip.org/link/?JAS/81/495/1> doi: 10.1121/1.394915
- Huffman, M. K. (1989). *Implementation of Nasal: Timing and Articulatory Landmarks* (Unpublished doctoral dissertation). University of California, Los Angeles.
- Ihaka, R., & Gentleman, R. (1996). R: A language for data analysis and graphics. *Journal of Computational and Graphical Statistics*, 5(3), 299-314.
- Iseli, M., Shue, Y.-L., & Alwan, A. (2007). Age, sex, and vowel dependencies of acoustic measures related to the voice source. *The Journal of the Acoustical Society of America*, 121(4), 2283-2295. Retrieved from <http://link.aip.org/link/?JAS/121/2283/1> doi: 10.1121/1.2697522
- Iskarous, K., Fowler, C. A., & Whalen, D. H. (2010). Locus equations are an acoustic expression of articulator synergy. *The Journal of the Acoustical Society of America*, 128(4), 2021-2032. Retrieved from <http://link.aip.org/link/?JAS/128/2021/1> doi: 10.1121/1.3479538
- Iskarous, K., Mooshammer, C., Hoole, P., Recasens, D., Shadle, C. H., Saltzman, E., & Whalen, D. H. (2013). The coarticulation/invariance scale: Mutual information as a measure of coarticulation resistance, motor synergy, and articulatory invariance. *The Journal of the Acoustical Society of America*, 134(2), 1271-1282. Retrieved from <http://link.aip.org/link/?JAS/134/1271/1> doi: 10.1121/1.4812855
- Jaeger, J. J. (1983). The fortis/lenis question: evidence from Zapotec and Jawoñ. *Journal of Phonetics*, 11, 177-189.
- Jakobson, R., & Halle, M. (1962). Tenseness and laxness. *Selected Writings of Roman Jakobson*, 1, 550-555.
- Jansen, W. (2004). *Laryngeal contrast and phonetic voicing: a laboratory phonology approach to English, Hungarian, and Dutch* (PhD Thesis). University of Groningen.
- Jernudd, B. (1974). Articulating Gunwinjgu laminals. In B. J. Blake

- (Ed.), *Papers in Australian Aboriginal Languages. (Linguistic Communications)* (Vol. 14, pp. 83–109). Melbourne: Monash University.
- Johnson, K. (2003). *Acoustic and Auditory Phonetics*. Malden, MA: Wiley-Blackwell.
- Jones, C., & Meakins, F. (2013). Variation in voice onset time in stops in Gurindji Kriol: Picture naming and conversational speech. *Australian Journal of Linguistics*, 33(2), 196-220. Retrieved from <http://www.tandfonline.com/doi/abs/10.1080/07268602.2013.814525> doi: 10.1080/07268602.2013.814525
- Jones, D. (1918). *An Outline of English Phonetics* (9th ed.). Cambridge: Heffer.
- Joos, M. (1948). Acoustic phonetics. *Language*, 24(2), 5-136.
- Kagaya, R. (1971). Laryngeal gestures in Korean stop consonants. *Annual Bulletin Research Institute of Logopedics and Phoniatics, University of Tokyo*, 5, 15–23.
- Kagaya, R. (1974). A fiberoptic and acoustic study of the Korean stops, affricates and fricatives. *Journal of Phonetics*, 2, 161–180.
- Kawasaki, H. (1986). Phonetic explanations for phonological universals: the case of distinctive vowel nasalisation. In J. Ohala & J. Jaeger (Eds.), *Experimental Phonology* (pp. 81–103). Orlando, Florida: Academic Press.
- Keane, E. (2001). *Echo Words in Tamil* (PhD Thesis). Merton College, Oxford.
- Keane, E. (2004). Tamil. *Journal of the International Phonetic Association*, 34(01), 111-116.
- Keating, P., Cho, T., Fougeron, C., & Hsu, C.-S. (1998). Domain-initial articulatory strengthening in four languages. In *Papers in Laboratory Phonology VI*. Cambridge University Press.
- Keating, P., Cho, T., Fougeron, C., & Hsu, C.-S. (2004). Domain-initial articulatory strengthening in four languages. In J. Local, R. Ogden, & R. Temple (Eds.), *Phonetic Interpretation* (Vol. VI, p. 145-163). Cambridge University Press. Retrieved from <http://dx.doi.org/10.1017/>

CB09780511486425

- Keating, P., Esposito, C., Garellek, M., Khan, S., & Kuang, J. (2012). Multi-dimensional phonetic space for phonation contrasts. In *Poster presented at LabPhon13 in Stuttgart, Germany, July, 2012*.
- Keating, P. A. (1987, February). Coarticulation and timing. *UCLA - Working Papers in Phonetics*, 69, 1-2.
- Keating, P. A. (1990). The window model of coarticulation: articulatory evidence. *Papers in Laboratory Phonology I: Between the Grammar and Physics of Speech*, 26, 451-470.
- Keating, P. A., Westbury, J. R., & Stevens, K. N. (1980). Mechanisms of stop-consonant release for different places of articulation. *The Journal of the Acoustical Society of America*, 67(S1), S93-S93. Retrieved from <http://link.aip.org/link/?JAS/67/S93/3> doi: 10.1121/1.2018489
- Khioe, F. W. (2004). *A Phonetic Study of Nasals and Nasalization in Hong Kong Chinese* (Masters Thesis). City University of Hong Kong.
- Kim, C.-W. (1970). A theory of aspiration. *Phonetica*, 21, 107-116.
- Kim, D., Hirose, H., & Niimi, S. (1992). A fiberoptic study of laryngeal gestures for Korean intervocalic stops. *Annual Bulletin of the Research Institute of Logopedics and Phoniatrics*, 26, 13-21.
- Kim, M. R., & Duanmu, S. (2004). "Tense" and "lax" stops in Korean. *Journal of East Asian Linguistics*, 13(1), 59-104.
- Kingston, J. (1983). Does a Bernoulli force cause velar double bursts? *The Journal of the Acoustical Society of America*, 74(S1), S51-S52. Retrieved from <http://link.aip.org/link/?JAS/74/S51/7> doi: 10.1121/1.2021016
- Kirchner, R. (2000). Geminate inalterability and lenition. *Language*, 76(3), 509-545.
- Klatt, D. H., Stevens, K. N., & Mead, J. (1968). Studies of articulatory activity and airflow during speech. *Annals of the New York Academy of Sciences*,

- 155(1), 42-55.
- Kloss, H. (1967, Oct). 'Abstand Languages' and 'Ausbau Languages'. *Anthropological Linguistics*, 9(7), 29-41.
- Kohler, K. J. (1984). Phonetic explanation in phonology: The feature fortis/lenis. *Phonetica*, 41(3), 150-174.
- Krakow, R., & Huffman, M. (1993). Instruments and techniques for investigating nasalization and velopharyngeal function in the laboratory: an introduction. In M. K. Huffman & R. A. Krakow (Eds.), *Nasals, Nasalization and the Velum* (Vol. 5, pp. 3-59). San Diego: Academic Press.
- Krull, D. (1987). Second formant locus patterns as a measure of consonant-vowel coarticulation. *Phonetic Experimental Research at the Institute of Linguistics*, 5, 43-61.
- Krull, D. (1989). Second formant locus patterns and consonant vowel coarticulation in spontaneous speech. *Phonetic Experimental Research Institute of Linguistics*, 10, 87-108.
- Kühnert, B., & Nolan, F. (1999). The origin of coarticulation. In W. J. Hardcastle & N. Hewlett (Eds.), *Coarticulation : theory, data and techniques*. Cambridge: CUP.
- Kurowski, K., & Blumstein, S. E. (1984). Perceptual integration of the murmur and formant transitions for place of articulation in nasal consonants. *The Journal of the Acoustical Society of America*, 76(2), 383-390. Retrieved from <http://link.aip.org/link/?JAS/76/383/1> doi: 10.1121/1.391139
- Ladefoged, P. (1964). *A Phonetic Study of West African Languages* (Vol. 1). Cambridge: Cambridge University Press.
- Ladefoged, P. (2003). *Phonetic Data Analysis: An Introduction to Fieldwork and Instrumental Techniques*. Malden: Blackwell Publishing.
- Ladefoged, P., & Everett, D. (1996). The status of phonetic rarities. *Language*, 72(4), 794-800.

- Ladefoged, P., & Maddieson, I. (1996). *Sounds of the World's Languages*. Oxford: Blackwell.
- Lahiri, A., & Hankamer, J. (1988). The timing of geminate consonants. *Journal of Phonetics*, 16, 327-338.
- Lawrence, S., Nolan, F., & McDougall, K. (2008). Acoustic and perceptual effects of telephone transmission on vowel quality. *International Journal of Speech Language and the Law*, 15(2), 161.
- Lehiste, I. (1970). *Suprasegmentals*. Cambridge, Mass.: MIT Press.
- Lehiste, I., Morton, K., & Tatham, M. (1973). An instrumental study of consonant gemination. *Journal of phonetics*, 1, 131-148.
- Lewis, M. P. (2009). *Ethnologue: Languages of the world* (Sixteenth ed.) [Journal/Newspaper, Online]. Dallas, Texas: Summer Institute of Linguistics. Retrieved from <http://www.sil.org/ethnologue> (Online version: <http://www.ethnologue.com/>)
- Liljencrants, J., & Lindblom, B. (1972). Numerical simulation of vowel quality systems: The role of perceptual contrast. *Language*, 839-862.
- Lindblom, B., Agwuele, A., Sussman, H. M., & Cortes, E. E. (2007). The effect of emphatic stress on consonant vowel coarticulation. *The Journal of the Acoustical Society of America*, 121, 3802.
- Lindblom, B., & Maddieson, I. (1988). Phonetic universals in consonant systems. In L. M. Hyman & C. N. Li (Eds.), *Language, speech and mind. studies in honour of Victoria A. Fromkin* (pp. 62-78). London: Routledge.
- Lisker, L. (1970). Supraglottal air pressure in the production of English stops. *Language and speech*, 13(4), 215-230.
- Lisker, L. (1974). On 'explaining' vowel duration variation. *Glossa*, 8, 223-246.
- Lisker, L. (1978). In qualified defense of VOT. *Language and Speech*, 21(4), 375-383. Retrieved from <https://ezp.lib.unimelb.edu.au/login?url=https://search-ebscohost-com.ezp.lib>

- .unimelb.edu.au/login.aspx?direct=true&db=a9h&AN=14089236&site=ehost-live
- Lisker, L., & Abramson, A. S. (1964). A cross linguistic study of voicing in initial stops: acoustical measurements. *Word*, 20, 384-422.
- Lo, J. W. (2010). *Possible Constraints On Allophonic Voicing In Australian Aboriginal Languages: Evidence From Bardi, Kayardild, Warlpiri, And Yan-Nhangu* (Honours Thesis). Yale University.
- Loakes, D., Butcher, A. R., Fletcher, J., & Stoakes, H. M. (2008). Phonetically prestopped laterals in Australian Languages: A preliminary investigation of Warlpiri. In *Interspeech*. Brisbane.
- Local, J., & Simpson, A. (1988). The domain of gemination in Malayalam. In D. Bradley, E. J. Henderson, & M. Mazaudon (Eds.), *Prosodic analysis and Asian Linguistics: to honour R.K. Sprigg* (pp. 33–42). Canberra: Australian National University.
- Local, J., & Simpson, A. P. (1999, 1-7 August). Phonetic implementation of geminates in Malayalam nouns. In J. J. Ohala, Y. Hasegawa, M. Ohala, D. Granville, & A. C. Bailey (Eds.), *The Proceedings of the 14th International Conference of Phonetic Sciences* (pp. 595–598). San Francisco.
- Löfqvist, A. (1999). Interarticulator phasing, locus equations, and degree of coarticulation. *The Journal of the Acoustical Society of America*, 106(4), 2022-2030.
- Löfqvist, A. (2012). Theories and models of speech production. In W. J. Hardcastle, J. Laver, & F. E. Gibbon (Eds.), *The Handbook of Phonetic Sciences* (2nd ed., Vol. 119, p. 353). Malden, Ma.: John Wiley & Sons.
- Lowe, B. (1963). *A Gupapuyngu grammar*. (Unpublished manuscript.)
- Lubker, J. (1973). Transglottal airflow during stop consonant production. *Journal of the Acoustical Society of America*, 53(1), 212. Retrieved from <https://ezp.lib.unimelb.edu.au/login?url=https://search-ebscohost-com.ezp.lib.unimelb.edu.au/login.aspx>

?direct=true&db=eda&AN=75074764&site=eds-live

- Maddieson, I. (1988). Prenasalized stops and speech timing (A). *The Journal of the Acoustical Society of America*, 83, S28.
- Maddieson, I. (1989, December). Prenasalized stops and speech timing. *Journal of the International Phonetic Association*, 19(2), 57-66.
- Maddieson, I. (1999a). Phonetic universals. In W. J. Hardcastle & J. Laver (Eds.), *The Handbook of Phonetic Sciences* (1st ed.). Massachusetts: Blackwell.
- Maddieson, I. (1999b). Strength matters. In J. J. Ohala, Y. Hasegawa, M. Ohala, D. Granville, & A. C. Bailey (Eds.), *14th International Congress of Phonetic Sciences* (Vol. 3, pp. 1965–68).
- Maddieson, I. (2001). Phonetic fieldwork. In P. Newman & M. Ratliff (Eds.), *Linguistic Fieldwork*. Cambridge: Cambridge University Press.
- Maddieson, I., & Disner, S. F. (Eds.). (1984). *Patterns of Sounds*. Cambridge: Cambridge University Press. Retrieved from <http://dx.doi.org/10.1017/CB09780511753459>
- Maddieson, I., & Ladefoged, P. (1993). Phonetics of partially nasal consonants. In M. K. Huffman & R. A. Krakow (Eds.), *Nasals, Nasalization and the Velum* (Vol. 5, p. 251-301). San Diego: Academic Press.
- Maddieson, I., & Larson, J. (2002). Variability in the production of glottalized sonorants: data from Yapese. In J. Hanson & B. Pellom (Eds.), *Proceedings of the 7th International Conference on Spoken Language Processing* (Vol. 2, p. 1097-1100). Denver, Colorado: ISCA.
- Malécot, A. (1955). An experimental study of force of articulation. *Studia Linguistica*, 9(1-2), 35-44.
- Malécot, A. (1956). Acoustic cues for nasal consonants: An experimental study involving a tape-splicing technique. *Language*, 32(2), 274–284.
- Malécot, A. (1966a). The effectiveness of intra-oral air-pressure-pulse parameters in distinguishing between stop cognates. *Phonetica*, 14, 65-81.

- Malécot, A. (1966b). Mechanical pressure as an index of force of articulation. *Phonetica*, 14, 169-180.
- Malécot, A. (1970). The lenis-fortis opposition: Its physiological parameters. *The Journal of the Acoustical Society of America*, 47(6B), 1588-1592.
- Manakgu, A., & Etherington, S. (1996). *Basic Kunwinjku Dictionary: A Simplified English-Kunwinjku and Kunwinjku-English Dictionary With Semantic Domain Listing*. The Kunwinjku Language Centre.
- Mark, D. M., & Turk, A. G. (2003). Landscape categories in Yindjibarndi: Ontology, environment, and language. In W. Kuhn, M. F. Worboys, & S. Timpf (Eds.), *Spatial Information Theory. Foundations of Geographic Information Science* (Vol. 2825, p. 28-45). Springer Berlin Heidelberg. Retrieved from http://dx.doi.org/10.1007/978-3-540-39923-0_3 doi: 10.1007/978-3-540-39923-0_3
- Martin, S. (1951). Korean phonemics. *Language*, 27(4), 519-533.
- Master, A. (1939). Intervocalic plosives in early Tamil. *Bulletin of the School of Oriental and African Studies, University of London*, 9(4), 1003-1008.
- MATLAB. (2012). *Version 7.14.0.739 (r2012a)*. Natick, Massachusetts: The MathWorks Inc.
- McConvell, P., & Meakins, F. (2005). Gurindji Kriol: A mixed language emerges from code-switching. *Australian Journal of Linguistics*, 25(1), 9-30.
- McGregor, B., William. (1990). *A Functional Grammar of Gooniyandi*. Amsterdam/Philidelphia: John Benjamins Publishing Co.
- McKay, G. (1980). Medial stop gemination in Rembarrnga: a spectrographic study. *Journal of Phonetics*, 8, 343-352.
- Mecke, A.-C., Sundberg, J., Granqvist, S., & Echternach, M. (2012). Comparing closed quotient in children singers' voices as measured by high-speed-imaging, electroglottography, and inverse filtering. *The Journal of the Acoustical Society of America*, 131(1), 435-441. Retrieved from <http://link.aip.org/link/?JAS/131/435/1> doi: 10.1121/1.3662061

- Merlan, F. (1983). *Ngalakan Grammar, Texts and Vocabulary*. Canberra: Pacific Linguistics.
- Merlan, F., & Rumsey, A. (1982). Jawoyn (Katherine Area) Land Claim: Anthropologists' Report. *Darwin, The Northern Land Council*.
- Michaud, A. (2004). A measurement from electroglottography: DECPA, and its application in prosody. In *Speech Prosody 2004, International Conference*.
- Miller, G., & Nicely, P. (1955). An analysis of perceptual confusions among some English consonants. *The Journal of the Acoustical Society of America*, 27, 338.
- Mithun, M. (1984). The evolution of noun incorporation. *Language*, 60(4), pp. 847-894. Retrieved from <http://www.jstor.org/stable/413800>
- Modarresi, G. (2002). *The effects of syllable boundary, stop consonant closure duration, and VOT on VCV coarticulation* (Unpublished doctoral dissertation). University of Texas.
- Modarresi, G., Sussman, H., Lindblom, B., & Burlingame, E. (2004). Stop place coding: an acoustic study of CV, VC#, and C#V sequences. *Phonetica*(61), 2-21.
- Modarresi, G., Sussman, H., Lindblom, B., & Burlingame, E. (2005). Locus equation encoding of stop place: revisiting the voicing/VOT issue. *Journal of Phonetics*, 33(1), 101-113.
- Morphy, F. (1983). Djapu, a Yolngu dialect. In R. M. W. Dixon & B. J. Blake (Eds.), (pp. 1-188). Amsterdam: John Benjamins.
- Müller, E. M., & Brown, W. S. J. (1980). Variations in the supraglottal air pressure waveform and their articulatory interpretation. In N. Lass (Ed.), *Speech and Language: Advances in Basic Research and Practice* (Vol. 4, p. 317-389). New York: Academic Press.
- Narayanan, S., Byrd, D., & Kaun, A. (1999). Geometry, kinematics, and acoustics of Tamil liquid consonants. *The Journal of the Acoustical Society of America*, 106, 1993.

- Nichols, J. (1986). Head-marking and dependent-marking grammar. *Language*, 56–119.
- Oates, L. F. (1964). A tentative description of the Gunwinggu language (of Western Arnhem Land). *Oceania Linguistic Monographs*, 10, 3–119.
- O'Grady, G. N., Voegelin, C. F., & Voegelin, F. M. (1966). Languages of the World: Indo-Pacific fascicle six. *Anthropological Linguistics*, 8(2).
- Ohala, J. J. (1975). Phonetic explanations for nasal sound patterns. In C. A. Ferguson, L. M. Hyman, & J. J. Ohala (Eds.), *Nasalfest: Papers from a symposium on nasals and nasalization* (p. 289 - 316). Stanford.
- Ohala, J. J. (1997). Aerodynamics of phonology. In *Proceedings of the Seoul International Conference on Linguistics* (pp. 92–97).
- Ohala, J. J., & Kawasaki, H. (1984). Prosodic phonology and phonetics. *Phonology*, 1(1), 113-127.
- Ohala, J. J., & Ohala, M. (1993). The phonetics of nasal phonology: theorems and data. *Phonetics and phonology*, 5, 225–249.
- Ohala, J. J., & Riordan, C. J. (1979). Passive vocal tract enlargement during voiced stops. *The Journal of the Acoustical Society of America*, 65, S23.
- Ohala, M. (1974). The abstractness controversy: Experimental input from Hindi. *Language*, 225–235.
- Ohde, R. N. (1984). Fundamental frequency as an acoustic correlate of stop consonant voicing. *The Journal of the Acoustical Society of America*, 75(1), 224-230.
- Öhman, S. E. G. (1966a). Coarticulation in VCV utterances: Spectrographic measurements. *The Journal of the Acoustical Society of America*, 39, 151.
- Öhman, S. E. G. (1966b). Perception of segments of VCCV utterances. *The Journal of the Acoustical Society of America*, 40(5), 979-988.
- Orlikoff, R. F., Baken, R. J., & Kraus, D. H. (1997). Acoustic and physiologic characteristics of inspiratory phonation. *The Journal of the Acoustical Society of America*, 102(3), 1838-1845. Retrieved from <http://>

- link.aip.org/link/?JAS/102/1838/1 doi: 10.1121/1.420090
- Pastore, R. E., & Farrington, S. M. (1996). Measuring the difference limen for identification of order of onset for complex auditory stimuli. *Perception & psychophysics*, 58(4), 510–526.
- Payne, E. M. (2006). Non-duration indices in Italian geminate consonants. *Journal of the International Phonetic Association*, 36(01), 83–95.
- Pentland, C. (2004). *Stress in Warlpiri: Stress Domains and Word-level Prosody* (Unpublished doctoral dissertation). School of English, Media Studies and Art History, University of Queensland.
- Pentland, C., & Laughren, M. (2004). Distinguishing prosodic word and phonological word in Warlpiri: Prosodic constituency in morphologically complex words. In *Proceedings of 2004 Conference of the Australian Linguistic Society*.
- Perkell, J. (1969). Physiology of speech production: results and implications of a quantitative cineradiographic study.
- Peterson, G., & Lehiste, I. (1960). Duration of syllable nuclei in English. *Journal of the Acoustical Society of America*, 32(1), 693-703.
- Pisoni, D. B. (1977). Identification and discrimination of the relative onset time of two component tones: Implications for voicing perception in stops. *The Journal of the Acoustical Society of America*, 61(5), 1352-1361. Retrieved from <http://link.aip.org/link/?JAS/61/1352/1> doi: 10.1121/1.381409
- Port, R. F., & Dalby, J. (1982). Consonant/vowel ratio as a cue for voicing in English. *Perception & Psychophysics*, 32(2), 141-152.
- Proffit, W. R., McGlone, R. E., & Barrett, M. J. (1973). Tongue and lip activity during Australian Aboriginal (Walbiri) articulation (A). *The Journal of the Acoustical Society of America*, 53(1), 295-295.
- Quené, H., & Van den Bergh, H. (2008). Examples of mixed-effects modeling with crossed random effects and with binomial data. *Journal of Memory*

- and Language*, 59(4), 413–425.
- R Core Team. (2014). R: A language and environment for statistical computing [Computer software manual]. Vienna, Austria. Retrieved from <http://www.R-project.org/> (ISBN 3-900051-07-0)
- Ramasubramanian, N., & Thosar, R. (1971). Synthesis by rule of some retroflex speech sounds. *Language and speech*, 14(1), 65–85.
- Recasens, D. (1983). Place cues for nasal consonants with special reference to Catalan. *Journal of the Acoustical Society of America*, 73(4), 1346–1353.
- Recasens, D. (1984). Vowel-to-vowel coarticulation in Catalan VCV sequences. *The Journal of the Acoustical Society of America*, 76(6), 1624–1635.
- Recasens, D. (1985). Coarticulatory patterns and degrees of coarticulatory resistance in Catalan CV sequences. *Language and Speech*, 28(2), 97–114.
- Recasens, D. (1989). Long range coarticulation effects for tongue dorsum contact in VCVCV sequences. *Speech Communication*, 8(4), 293–307.
- Recasens, D. (2004). The effect of syllable position on consonant reduction (evidence from Catalan consonant clusters). *Journal of Phonetics*, 32, 435–453.
- Recasens, D., & Espinosa, A. (2009). An articulatory investigation of lingual coarticulatory resistance and aggressiveness for consonants and vowels in Catalan. *The Journal of the Acoustical Society of America*, 125(4), 2288–2298. Retrieved from <http://link.aip.org/link/?JAS/125/2288/1> doi: 10.1121/1.3089222
- Recasens, D., & Pallarès, M. D. (2001). Coarticulation, assimilation and blending in catalan consonant clusters. *Journal of Phonetics*, 29(3), 273–301.
- Recasens, D., Pallares, M. D., & Fontdevila, J. (1997). A model of lingual coarticulation based on articulatory constraints. *The Journal of the Acoustical Society of America*, 102(1), 544–561. Retrieved from <http://link.aip.org/link/?JAS/102/544/1> doi: 10.1121/1.419727
- Reid, N. (1982). *The basic morphology of Ngangikurunggurr* (Honours sub-thesis,

- Ms 1752, AIATSIS). Australian National University, Canberra.
- Ridouane, R. (2003). *Suites de Consonnes en Berbère: Phonétique et Phonologie* (PhD. Dissertation). Sorbonne Nouvelle University, Paris 3.
- Ridouane, R. (2007). Gemination in Tashlhiyt Berber: an acoustic and articulatory study. *Journal of the International Phonetic Association*, 37(02), 119-142.
- Ridouane, R. (2008). Geminate consonants at the junction of phonetics and phonology. In *Laboratory Phonology 10*. Berlin: Mouton de Gruyter.
- Ridouane, R., Fuchs, S., & Hoole, P. (2006). Laryngeal adjustments in the production of voiceless obstruent clusters in Berber. In J. Harrington & M. Tabain (Eds.), *Speech Production: Models, Phonetic Processes and Techniques* (chap. 16). New York: Psychology Press.
- Riehl, A. K. (2008). *The Phonology and Phonetics of Nasal Obstruent Sequences* (PhD Thesis). Cornell University.
- Riehl, A. K., & Cohn, A. C. (2011). Partially nasal segments. In E. H. Marc van Oostendorp Colin J. Ewen & K. Rice (Eds.), *The Blackwell Companion to Phonology*. Blackwell Publishing Ltd.
- Ross, B. (2011). *Prosody and Grammar in Dalabon and Kayardild* (Unpublished doctoral dissertation). School of Languages and Linguistics: The University of Melbourne.
- Rothenberg, M. (1968). The breath-stream dynamics of simple-released-plosive production. *Biblioteca Phonetica*, 6.
- Rothenberg, M. (2009). Voice onset time versus articulatory modeling for stop consonants. *Logopedics Phoniatrics Vocology*, 34(4), 171–180.
- Rothenberg, M., & Mahshie, J. J. (1988). Monitoring vocal fold abduction through vocal fold contact area. *Journal of Speech and Hearing Research*, 31(3), 338-351.
- Sadanand, K. (1992). Long stop consonants in Punjabi - an instrumental investigation. In T. Balasubramanian & V. Prakasam (Eds.), *Sound Patterns for*

- the Phonetician: Studies in Phonetics and Phonology in Honour of J.C. Catford* (pp. 83–104). TR Publications.
- Saïb, J. (1974). Gemination and spirantization in Berber: Diachrony and synchrony. *Studies in African Linguistics*, 5(1), 1-26.
- Saïb, J. (1977). The treatment of geminates: evidence from Berber. *Studies in African Linguistics*, 8(3), 299-316.
- Saltzman, E., & Byrd, D. (2000). Task-dynamics of gestural timing: Phase windows and multifrequency rhythms. *Human Movement Science*, 19(4), 499 - 526. Retrieved from <http://www.sciencedirect.com/science/article/B6V8T-42FS2BR-5/2/48088aad85f61ff641c43605f668ccaf> doi: DOI:10.1016/S0167-9457(00)00030-0
- Saltzman, E. L., & Munhall, K. G. (1989). A dynamical approach to gestural patterning. *Ecological Psychology*, 1(4), 333-82.
- Saltzman, E. L., Rubin, P. E., Goldstein, L., & Browman, C. P. (1987). Task-dynamic modeling of interarticulator coordination (A). *The Journal of the Acoustical Society of America*, 82(S1), S15-S15.
- Sandefur, J., & Jentian, D. (1977). A tentative description of the phonemes of the Ngalkbun language (including a small word list). *Five papers in Australian phonologies*, 57–96.
- Sawashima, M., & Hirose, H. (1983). Laryngeal gestures in speech production. In P. F. MacNeilage (Ed.), *The Production of Speech* (p. 11-38). New York: Springer-Verlag.
- Schebeck, B. (n.d.). *The glottal stop in NE Arnhem Land*. (AIATSIS PM1529)
- Schebeck, B. (1968). *Final report on linguistic fieldwork carried out under a research grant from the A.I.A.S. from 23rd Nov. 1964 until 31st March 1967.(Yolngu)* (Tech. Rep.). AIAS m.s. 353.
- Schebeck, B. (2001). *Dialect and Social Groupings in Northeast Arnhem [ie Arnhem] Land*. LINCOM Europa.

- Scobbie, J. M. (2006). Flexibility in the face of incompatible English VOT systems. In L. M. Goldstein, C. Best, & D. Whalen (Eds.), *Papers in Laboratory Phonology 8: Varieties of Phonological Competence* (Vol. 8). Berlin: Mouton de Gruyter.
- Shadle, C. H. (2013). The aerodynamics of speech. In W. J. Hardcastle, J. Laver, & F. E. Gibbon (Eds.), *The Handbook of Phonetic Sciences* (p. 39). Chichester, U.K.: John Wiley & Sons Ltd.
- Shin, J.-H. (1994). Acoustic features differentiating Korean medial tense and lax stops. *The Journal of the Acoustical Society of America*, 96(5), 3229-3230. Retrieved from <http://link.aip.org/link/?JAS/96/3229/6> doi: 10.1121/1.411168
- Shue, Y., Keating, P., Vicenik, C., & Yu, K. (2011). Voicesauce: A program for voice analysis. In *Proceedings of the 17th International Congress of Phonetic Sciences* (p. 1846). Hong Kong, China.
- Shue, Y.-L., Keating, P., & Vicenik, C. (2009). Voicesauce: A program for voice analysis. *The Journal of the Acoustical Society of America*, 126(4), 2221-2221. Retrieved from <http://link.aip.org/link/?JAS/126/2221/2> doi: 10.1121/1.3248865
- Smith, C. L. (1995). Prosodic patterns in the coordination of vowel and consonant gestures. In B. Connell & A. Arvaniti (Eds.), *Papers in laboratory phonology IV: Phonology and phonetic evidence* (p. 205-222).
- Sommer, B. (1970). An Australian language without CV syllables. *Journal of American Linguistics*, 36(1), 57-58.
- Stetson, R. (1951). *Motor phonetics; a study of speech movements in action*. (2nd ed.). Oxford, England: North-Holland Publishing Co.
- Stevens, K., & Hanson, H. (1995). Classification of glottal vibration from acoustic measurements. In O. Fujimura & M. Hirano (Eds.), *Vocal Fold Physiology: voice quality control* (pp. 147-170). San Diego, California: Singular Publishing Group.

- Stevens, K. N. (1998). *Acoustic Phonetics*. Cambridge, Mass.: MIT Press.
- Stevens, K. N. (1999). Articulatory-acoustic-auditory relationships. In W. J. Hardcastle & J. Laver (Eds.), *The Handbook of Phonetic Sciences* (1st ed.). Massachusetts: Blackwell.
- Stevens, K. N., Keyser, S. J., & Kawasaki, H. (1986). Toward a phonetic and phonological theory of redundant features. *Invariance and variability in speech processes*, 426–449.
- Stevens, M. E. (2007). *A Phonetic Investigation Into Raddoppiamento Sintattico in Sienese Italian Speech* (PhD Thesis). The School of Languages and Linguistics, The University of Melbourne.
- Stoakes, H. M., Butcher, A. R., Fletcher, J. M., & Tabain, M. (2012). Place or manner as perceptually salient in Yolngu Matha: A closed set 4-AFC listening task in quiet and in noise. In F. Cox, K. Demuth, S. Lin, K. Miles, & S. Palethorpe (Eds.), *Proceedings of the 14th Speech Science and Technology Conference, Sydney* (p. 225-228).
- Street, C. S., & Mollinjin, G. P. (1981). The phonology of Murinbata. *Work Papers of SIL-ABB, A-5*, 183–244.
- Subtelny, J. D., Worth, J. H., & Sakuda, M. (1966). Intraoral pressure and rate of flow during speech. *Journal of Speech and Hearing Research*, 9(4), 498-518. Retrieved from <http://jslhr.asha.org/cgi/content/abstract/9/4/498>
- Sundberg, J., Andersson, M., & Hultqvist, C. (1999). Effects of subglottal pressure variation on professional baritone singers' voice sources. *The Journal of the Acoustical Society of America*, 105(3), 1965-1971. Retrieved from <http://link.aip.org/link/?JAS/105/1965/1> doi: 10.1121/1.426731
- Sussman, H. M. (1991). The representation of stop consonants in three-dimensional acoustic space. *Phonetica*, 48(1), 18–31.
- Sussman, H. M., Dalston, E., & S., G. (1998). The effect of speaking style on

- a locus equation characterization of stop place of articulation. *Phonetica*, 55, 204-225.
- Sussman, H. M., Fruchter, D., Hilbert, J., & Sirosh, J. (1998). Linear correlates in the speech signal: The orderly output constraint. *Behavioral and Brain Sciences*, 21(02), 241-259. Retrieved from <http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=29983&fulltextType=RA&fileId=S0140525X98001174>
- Sussman, H. M., Hoemeke, K. A., & Ahmed, F. S. (1993). A cross-linguistic investigation of locus equations as a phonetic descriptor for place of articulation. *The Journal of the Acoustical Society of America*, 94(3), 1256-1268.
- Sussman, H. M., McCaffrey, H. A., & Matthews, S. A. (1991, September). An investigation of locus equations as a source of relational invariance for stop place categorization. *The Journal of the Acoustical Society of America*, 90(3), 1309-1325.
- Sweet, H. (1906). *A Primer in Phonetics*. Oxford: Clarendon Press.
- Tabain, M. (2000). Coarticulation in CV syllables: A comparison of locus equation and EPG data. *Journal of Phonetics*, 28(2), 137-159.
- Tabain, M. (2002). Voiceless consonants and locus equations: a comparison with electropalatographic data on coarticulation. *Phonetica*, 59(1), 20-37.
- Tabain, M. (2009). An EPG study of the alveolar vs. retroflex apical contrast in Central Arrernte. *Journal of Phonetics*, 37(4), 486-501.
- Tabain, M. (2012). Jaw movement and coronal stop spectra in Central Arrernte. *Journal of Phonetics*, 40(4), 551 - 567. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0095447012000241> doi: 10.1016/j.wocn.2012.03.003
- Tabain, M., & Beare, R. (2011). A Spectral Analysis of Stop Bursts in Pitjantjatjara. In *17th International Congress of the Phonetics Sciences, Hong Kong: China* (pp. 1934-1937).

- Tabain, M., & Breen, G. (2011). Central vowels in Central Arrernte: A spectrographic study of a small vowel system. *Journal of Phonetics*, 39(1), 68–84. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0095447010000896> doi: <http://dx.doi.org/10.1016/j.wocn.2010.11.004>
- Tabain, M., Breen, G., & Butcher, A. R. (2003). VC vs. CV syllables: a comparison of Aboriginal languages with English. In *6th International Seminar on Speech Production*. Sydney, Australia.
- Tabain, M., Breen, G., & Butcher, A. R. (2004). VC vs. CV syllables: a comparison of Aboriginal languages with English. *Journal of the International Phonetic Association*, 34(2), 175–199.
- Tabain, M., & Butcher, A. R. (1999a). Slope values as acoustic measures of coarticulation: a cross-language comparison of stop consonants. *Journal of Phonetics*, 25, 333–357.
- Tabain, M., & Butcher, A. R. (1999b). Stop consonants in Yanyuwa and Yindjibarndi: Locus equation data. *Journal of Phonetics*, 27(1), 333–357.
- Tabain, M., & Fletcher, J. (2012). A preliminary study of intonation in Pitjantjatjara. In *Proceedings of the 14th Speech Science and Technology Conference, Sydney*.
- Tabain, M., Fletcher, J., & Butcher, A. (2011). An EPG study of palatal consonants in two Australian languages. *Language and Speech*, 54(2), 265–282.
- Tehrani, H. (2011). *EggWorks: A program for automated analysis of EGG signals*. Retrieved from <http://www.linguistics.ucla.edu/facilities/facilities/physiology/EggWorksSetup.exeS>
- Telfer, W., & Garde, M. (2006). Indigenous knowledge of rock kangaroo ecology in Western Arnhem Land, Australia. *Human Ecology*, 34(3), 379–406.
- The Australian Bureau of Statistics. (2011). *Census dictionary 2011: Classifications index* (Tech. Rep.). Australian Bureau of Statistics.
- Thomas, G., & Finney, R. (1984). *Calculus and Analytic Geometry*. Reading:

- Addison-Wesley.
- Trefry, D. (1983). Discerning the back vowels /u/ and /o/ in Burrara, a language of the Northern Territory. *Working Papers of the Speech and Language Research Centre Macquarie University*, 3(6), 19-51.
- Tryon, D. (1970). *An introduction to Maranungku (Northern Australia)*. Australian National University. Retrieved from <http://books.google.com.au/books?id=xSMaQAAlAAJ>
- Tryon, D. T. (1974). *Daly Family Languages* (Vol. C-32). Canberra: Pacific Linguistics.
- Tserdanelis, G., & Arvaniti, A. (2001). The acoustic characteristics of geminate consonants in Cypriot Greek. *Proceedings of the Fourth International Conference on Greek Linguistics*, 17-19.
- van den Berg, J. (1958). Myoelastic-aerodynamic theory of voice production. *The Journal of Speech & Hearing Research*, 1(3), 227-244. Retrieved from <http://jslhr.asha.org/cgi/reprint/1/3/227.pdf>
- Walker, A. (1984, June). *The Yolngu stop controversy: Wood's prosodic hypothesis revisited*. (Paper delivered at the ALS annual conference, Alice Springs)
- Walsh, M. (1976). *The Murinypata Language of North-West Australia* (PhD Thesis). Australian National University, Canberra.
- Warren, D., Dalston, R., & Mayo, R. (1993). Aerodynamics of nasalization. In M. K. Huffman & R. A. Krakow (Eds.), *Nasals, Nasalization and the Velum* (Vol. 5, pp. 119-146). Academic Press.
- Warren, D. W. (1976). Aerodynamics of speech production. *Contemporary Issues in Experimental Phonetics*, 30, 105-137.
- Waters, B. E. (1984). *Djinang and Djinba—a grammatical and historical perspective* (Unpublished master's thesis). Australian National University, Canberra.
- Watkins, J. (1997). Can phonation types be reliably measured from sound spectra? Some data from Wa and Burmese. *SOAS Working Papers in Linguistics and Phonetics*, 7, 321-339.

- Wells, J. C. (1990). Syllabification and allophony. *Studies in the Pronunciation of English, a Commemorative Volume in Honour of AC Gimson*. London: Routledge, 76–86.
- Westbury, J., & Keating, P. (1986). On the naturalness of stop consonant voicing. *Journal of Linguistics*, 22, 145-166.
- Westbury, J. R. (1983). Enlargement of the supraglottal cavity and its relation to stop consonant voicing. *The Journal of the Acoustical Society of America*, 73(4), 1322-1336. Retrieved from <http://link.aip.org/link/?JAS/73/1322/1> doi: 10.1121/1.389236
- Wickham, H. (2009). *ggplot2: Elegant graphics for data analysis*. Springer Publishing Company, Incorporated.
- Wilkinson, L. (2005). *The Grammar of Graphics* (2nd ed.). Springer.
- Wilkinson, M. P. (1991). *Djambarrpuynu: A Yolŋu Variety of Northern Australia* (PhD Thesis). The Department of Linguistics, The University of Sydney.
- Wilks, S. S. (1938, 03). The large-sample distribution of the likelihood ratio for testing composite hypotheses. *The Annals of Mathematical Statistics*, 9(1), 60–62. Retrieved from <http://dx.doi.org/10.1214/aoms/1177732360> doi: 10.1214/aoms/1177732360
- Williams, D., & Williams, D. (2001). *Weighing the Odds: a Course in Probability and Statistics* (Vol. 548). Springer.
- Wilson, A. (2005). *The Changing Scene : Autobiography of Alf Wilson and his work in the Northern Territory* [Book]. Acacia Printing, Humpty Doo, N.T.
- Winter, B. (2013). *Linear models and linear mixed effects models in R*. Retrieved February 2014, from <http://arxiv.org/pdf/1308.5499.pdf>
- Wood, R. (1977). Some aspects of Galpu phonology. *Talanya*, 4, 24-29.
- Wood, R. (1978). Some Yuulngu phonological patterns. *Papers in Australian Linguistics*, A-51(11), 53-117.
- Wurm, S. A. (1972). *Languages of Australia and Tasmania*. The Hague: Mouton.
- Yanagihara, N., & Hyde, C. (1966). An aerodynamic study of the articulatory

- mechanism in the production of bilabial stop consonants. *Studia Phonologica*, IV, 70–80.
- Yoshioka, H., Löfqvist, A., Hirose, H., & Collier, R. (1986). How voiceless sound sequences are organized in terms of glottal opening gestures. *Annual Bulletin Research Institute of Logopedics and Phoniatics, University of Tokyo*(20), 55-67.
- Zvelebil, K. V. (1970). *Comparative Dravidian Phonology*. The Hague: Mouton.

Appendix A

Abbreviations and Conversions:

A.1 Abbreviations

ABBREVIATION	TERM
BGW	Bininj Gun-wok
DFT	Discrete Fourier Transform
DCT	Discrete Cosine Transform
EGG	Electroglottography
EPG	Electropalatography
FFT	Fast Fourier Transform
IPA	International Phonetic Alphabet
POA	Place of Articulation
VOT	Voice Onset Time
VTT	Voice Termination Time

A.2 Phonological Abbreviations

ABBREVIATION	TERM
C	Consonant (Oral consonant unless otherwise specified)
C:	Long consonant
N	Nasal
V	Vowel
L	Liquid
R	Rhotic
\$	Syllable boundary
.	Morpheme boundary

A.3 Kinship

ABBREVIATION	TERM
M	mother
F	father
Z	sister
B	brother
S	son
D	daughter
e	elder
y	younger
MM	mother's mother
FM	father's mother
MF	mother's father
FF	father's father
MFB	mother's father's brother
MFZ	mother's father's brother
C	child
sib	sibling
f	female
m	male

A.4 Interlinear Glossing

Glossing is according to the Leipzig Glossing Rules (MPI):

ABBREVIATION	TERM
BEN	Benefactive applicative
DEM	Demonstrative
1	First Person
2	Second Person
2/3	Second or Third Person
sg.	Singular
NEG	Negative
FUT	Future
GEN	Genitive
PST	Past
NP	Non-Past
PROH	Prohibitive
I	Noun Class (usually masculine)
II	Noun Class (usually feminine)
III	Noun Class (usually vegetable)
IV	Noun Class (usually neuter)
masc.	Masculine (pronoun) - M in LGR
fem.	Feminine (pronoun) - F in LGR

- Bickel, Balthasar, Comrie, B, Haspelmath, M. (2008). "The Leipzig Glossing Rules. Conventions for Interlinear Morpheme by Morpheme Glosses.". Dept. of Linguistics, Max Planck Institute,

http://www.eva.mpg.de/lingua/tools-at-lingboard/glossing_rules.php Retrieved 2013-11-20.

A.5 Acoustic and Aerodynamic Channels and Signals

ABBREVIATION	TERM
F_0	Fundamental Frequency
F_1	Formant 1
F_2	Formant 2
F_3	Formant 3
F_4	Formant 4
F_x	Fundamental Frequency derived from L_x
U_o	Peak Oral airflow
P_o	Peak intra-oral pressure
U_n	Peak nasal airflow
L_x	Laryngograph, high frequency signal
G_x	Laryngograph, low frequency signal
$f'U_o$	first derivative of oral airflow
$f'P_o$	first derivative of intra-oral pressure
$f'U_n$	first derivative of nasal airflow

A.6 Aerodynamic Unit Conversions

Pressure:

- $1 \text{ cm H}_2\text{O} = 98 \text{ Pa}$

Flow:

- $60 \text{ l/min} = 1 \text{ l/s} = 1000 \text{ ml/s} = 1000 \text{ cm}^3 \text{ s}^{-1}$

A.7 Acoustics

Frequency:

- $1000 \text{ Hz} = 1 \text{ kHz}$

A.8 Orthography

The orthographies for each dialect which is shown in Tables A.1, A.2 and A.3 were developed by consultant linguists and consequently employ different conventions for the representation of clusters. Kunwinjku is the most economic in its graphemic inventory and regardless of the position of the phoneme in a word uses a consistent set of symbols. The ⟨b⟩, ⟨d⟩, ⟨rd⟩ and ⟨dj⟩ and ⟨k⟩ graphemes and it should be noted that this is combining symbols that traditionally denote voiced stops (⟨b⟩, ⟨d⟩, ⟨rd⟩ and ⟨j⟩) with a voiceless symbol (⟨k⟩). When a long stop is represented the symbol is repeated except in the case of the retroflex long stop which is represented as ⟨rdd⟩ rather than ⟨rdrd⟩ shown in Table A.1.

In Kunwinjku it is not possible to distinguish orthographically between ‘true long stops’ which are called fortis in this analysis and geminate stops, homorganic clusters of stops spanning a morpheme boundary. In other dialects it is possible to differentiate them, as voiced graphemes are used for syllable initial phonemes and voiceless for syllable final phonemes such as in Manyallaluk Mayali shown in Table A.3.

TABLE A.1: *Orthographic system for Kunwinjku (Bininj Gun-wok) (from Evans, 2003).*

	BILABIAL	VELAR	PALATAL	ALVEOLAR	RETROFLEX	GLOTTAL
SHORT	b	k	dj	d	rd	h
LONG	bb	kk	djdj	dd	rdd	

TABLE A.2: *Orthographic system for Gundjeihmi (Bininj Gun-wok) (from Evans, 2003).*

	BILABIAL	VELAR	PALATAL	ALVEOLAR	RETROFLEX	GLOTTAL
SHORT	b	k,g	dj	d	rd	h
LONG	bb	kk	djdj	dd	rdd	

TABLE A.3: *Orthographic system for Manyallaluk Mayali (Bininj Gun-wok) (from Evans, 2003).*

	BILABIAL	VELAR	PALATAL	ALVEOLAR	RETROFLEX	GLOTTAL
SHORT	b,p	k,g	j,tj	d	rd,rt	'
LONG	pb	kg	tjj	td	rtd	

Appendix B

Word Lists:

B.1 Corpus I

Compiled by Andrew Butcher and Murray Garde October, 1990 Revised July, 2005.

ID	WORD	PHONETIC	GLOSS
	balaballa	bələp:ələ	table (Macassan loan)
	nabang	nəbeŋ	it's cheeky
	kardab	kəteb	spider
	bininj	bɪnɪŋ	man
	yibidbu	jɪbɪdɒ	you climb up!
	berk	bək	death adder
	moliblib	məlɪblɪb	piwi
	bibom	bɪbɔm	he hit him
	bokenh	bəkən?	two
	bukbuk	bukbuk	pheasant coucal (<i>Centropus phasianinus</i>)
	bobo	bɔbɔ	goodbye

Continued on next page

Table B.1 Continued from previous page

ID	WORD	PHONETIC	GLOSS
	dabuno	dəbunɔ	egg
	ngabbard	ŋep:ət	father
	malambibbi	mələmbɪpɪ	small bat sp.
	wubbunj	wup:ɔŋ	canoe (Macassan loan)
	dolobbo	dɔlɔp:ɔ	bark
	kabbal	kɛp:əl	flood plain
	djobbo	cɔp:ɔ	butcherbird (<i>Cracticus</i> sp.)
	kang	kɛŋ	he took it
	kakan	kɛkən	he's taking it
	ngardbakan	ŋɛɾbɛkən	mud mussels
	kunmak	kunmɛk	good
	kinhkinh	kɪnʔkɪnʔ	star(s)
	kakirh	kɛkɪrʔ	it's soft
	bikibiki	bɪkɪbɪkɪ	pig
	kokok	kɔkɔk	eB
	dukula	dɔkule	possum sp.
	mankongko	mɛnkɔŋkɔ	wild peanut
	kunkuk	kunkuk	body
	makka	mɛk:ɛ	FM
	kakkak	kɛk:ɛk	MM
	bekka	bɛk:ɛ	file snake
	bukkurlurɪ	buk:ɔɭɔɭ	full moon
	woybukki	wɔɪbukɪ	true
	yekke	jek:ɛ	dry season
	kikkik	kɪk:ɪk	lt. brown honeyeater

Continued on next page

Table B.1 Continued from previous page

ID	WORD	PHONETIC	GLOSS
	daluk	dəluk	woman
	kundad	kundəd	thigh/leg
	dird	dɪɾ	moon
	kadi	kədɪ	he's there (standing)
	yidok	jɪdɔk	is it true that...
	kunbid	kunbɪd	hand, fingers
	duruk	duruk	dog
	ngadong	ŋədɔŋ	I am hitting it (<i>manwarre</i>)
	kundjud	kuncud	nape of neck
	kaddum	kət:um	above
	djaddi	cətɪ	frog
	ngudda	ŋot:ə	you
	bedda	bət:ə	they
	yibiddi	jɪbɪtɪ	you're raising your hand
	djarduk	cətuk	red bush apple
	karrabarda	kerebeɾə	yam sp.
	kunbard	kunbeɾ	knee
	birdi	bɪɾɪ	beeswax
	djakirdinj	cəkɪɾɪŋ	s/w catfish
	kunberd	kunbeɾ	tail
	wurdurd	wɔɾɔɾ	children
	nangordo	nəŋɔɾɔ	leper
	kunkurduk	kunkɔɾuk	black
	bord	bɔɾ	fly
	dord	dɔɾ	louse

Continued on next page

Table B.1 Continued from previous page

ID	WORD	PHONETIC	GLOSS
	ngardduk	ŋɛtːʊk	my/mine
	kunmarddardda	kunmɛtːɛtːɛ	collar bone
	kundurddu	kundʊtːʊ	heart
	kunwardde	kunwɛtːɛ	rock/money
	djak	cɛk	red ant
	yidjare	jɪcɛɛ	you want
	ngalbadjan	ŋɛlbɛcɛn	mother
	ngadjadj	ŋɛcɛc	MB
	djila	cɪɛ	salt
	didjerok	dɪcɛrɔk	water tree
	yidjirridjbu	jɪcɪrɪcɪbʊ	wash it!
	manbedje	mɛnbɛcɛ	spear grass
	kundedj	kundɛc	buttocks
	djungkay	cʊŋkɛj	ceremonial boss
	nakodjok	nɛkɔcɔk	skin name
	budjulung	bucʊlʊŋ	bottle (Macassan loan)
	kunkodj	kunkɔc	head
	kodjdjan	kɔcːɛn	(skin name)
	yirridjdja	jɪrɪcɛ	(moiety)
	birradjdja	bɪrɛcɛ	rice (Macassan loan)
	mang	mɛŋ	I will get you
	kamak	kɛmɛk	it's good
	ngamang	ŋɛmɛŋ	I'll get him
	mamamh	mɛmɛm?	FM or FMB
	med	mɛd	wait

Continued on next page

Table B.1 Continued from previous page

ID	WORD	PHONETIC	GLOSS
	mirrhno	mirʔno	sharp
	kunmim	kunmim	eye
	yingimiwemen	jiŋimiwemen	put it in!
	narangem	nereŋem	male
	murru	moɾu	black fl.fox
	kumoken	kuməken	f/w crocodile (<i>Crocodylus johnstoni</i>)
	kumurrng	kumorŋ	v. early morning
	kunkom	kunkom	neck throat
	ngalanj	ŋeleŋ	finger nail
	ngangun	ŋeŋun	I eat
	nangahnang	neŋeʔneŋ	I saw you
	djang	ceŋ	dreaming site
	ngimeng	ŋimeŋ	it went in
	kundenge	kundeŋe	foot
	ningihni	niŋiʔni	he was there (sitting)
	birriweng	biɾiweŋ	they threw it away
	nguneng	ŋuneŋ	he ate
	yibongun	jiɓoŋun	you are drinking
	munguyh	moŋujʔ	for a long time
	kundung	kundoŋ	sun
	namekke	neɱekːe	that man
	banambi	benembɾi	fishing net
	kanan	kenen	he looks at it
	kulkanem	kunkənem	ears

Continued on next page

Table B.1 Continued from previous page

ID	WORD	PHONETIC	GLOSS
	ni	ni	to sit
	yinin	jɪnɪn	sit there!
	kundjen	kɒncɛn	tongue
	nungka	nɒŋkɛ	him
	kunnunj	kɒnnɒŋ	saliva
	kunnud	kɒnnɒd	pus
	ngunbun	ŋɒnbun	he hits you
	marnedjare	mɛŋɛɛɛɛ	I love you
	yibarname	jɪbɛŋɛmɛ	put it up
	ngalyod	ŋɛljɔd	Rainbow Serpent
Concluded			

B.2 Corpus II

Compiled by Hywel Stoakes with reference to Garde (in press), Etherington and Etherington (1998), Manakgu and Etherington (1996), Evans (2003) and Carroll (1976). Species names from Garde (in press).

ID	WORD	PHONETIC	GLOSS
A01	kabbal	kɛp:ɛl	flood plain
A02	ngabbard	ŋɛp:ɛɭ	father
A03	kubbunj	kɒp:ɒŋ	canoe
A04	kaddum	kɛt:ɒm	up, above
A05	bedda	bɛt:ɛ	they, them
A06	kunwardde	ˌkɒn'wɛɾ:tɛ	rock, money

Continued on next page

Table B.2 Continued from previous page

ID	WORD	PHONETIC	GLOSS
A07	dardda	dəɾɿə	younger brother (yB)
A08	ngalkodjdjan	(ŋ)əl'kɔc:ən	skin name (female)
A09	kakkak	'kək:ək	MM or MMB or SC/DC
A10	yekke	'jek:ε	cool season
B01	bakbakkeng	bək:'bæg,kɛŋ	break into pieces
B02	mekke	'mɛk:ε	DEM
B03	manekke	'mɛ,nɛk:ε	that one DEM
B04	kakid	'gɛuɿd	sick from sorcery
B05	kabo	'gɛβɔ	green ant
B06	bobo	'bɔbɔ	goodbye
B07	kakid	'gɛuɿd	sick from sorcery
B08	dalkken	'dɛlk:ɛn	dingo
B09	djorrkun	'cɔrk:ʊn	possum sp.
B10	kakan	'gɛgɛn	he's taking it
B11	djarduk	'cɛɖuk	red apple
B12	kokok	'uɖuɖɔk ʔ	elder brother (eB)
B13	yidjare	jɿɾɛ	you want
C01	kebbaldjurri	kɛ'p:ɛl'ɕuri	Royal Spoon Bill (<i>Platalea regia</i>)
C02	kebbalhmeng	kɛ'p:ɛlʔmɛŋ	close your nose!
C03	kebberrɛlh	'kɛp:ɛɛl	flat nosed
C04	kebongdong	kɛ'bɔŋdɔŋ	bring two noses together
C05	kebumeng	'kɛbɔmɛŋ	sulk away
C06	kebdjined	'kɛpɿnɛd	snot/jellyfish

Continued on next page

Table B.2 Continued from previous page

ID	WORD	PHONETIC	GLOSS
C07	kebdubberranj	kɛp'dup:ɛɾɛɲ	blocked nose
C08	kukebkali	gu'kɛp _l kɛlɪ	geographical ridge/point
C09	kebkuk	'kɛbkuk	liar
C10	kebebek	kɛ'bɛbɛk	separately
C11	kebkimuk	'kɛpkimuk	big nose
C12	kebyauhud	kɛb'jɛ ^w ʔ ^w ud	small nose
C13	kukak	'gugɛk	night
C14	kukabel	gu'gebel	early morning
D01	lodkimuk	'lɔtkimuk	s.t with a cylindrical shape
D02	kebkimuk	kɛpkimuk	big nosed (esp. of crocodile)
D03	nakukkimuk	nɛguk:imuk	big man
D04	kukkimuk	guk:imuk	big thing
D05	naburrrkimuk	nɛburkimuk	fat man
D06	mandulkkimuk	mentul:kimuk	big tree
D07	manbokimuk	mɛnbogimuk	big body of water
D08	bidyawkimuk	bidja ^w gimuk	thumb
D09	njamkimuk	ɲɛmgimuk	big gutted (lit. big intestines)
D10	mandulkkimuk	mentul:kimuk	big tree
E01	badbong	pɛtpɔŋ	rock wallaby sp.
E02	njarlkkan	'ɲɛl'k:ɛn	orchid (<i>Cymbidium</i> sp.)
E03	njarlkan	'ɲɛl'gɛn	archerfish (<i>Toxotes</i> sp.)
Nasal Word List			
N01	bininj	pɪɲɪɲ	male

Continued on next page

Table B.2 Continued from previous page

ID	WORD	PHONETIC	GLOSS
N02	kunak	kunək	fire
N03	kahdi	kəʔdɪ	he's standing there
N04	kamak	kemək	good
N05	kunkeb	kunkeb	nose
N06	kumoken	kumoken	Fresh Water Crocodile (<i>Crocodylus johnstoni</i>)
N07	kangkinj	kəŋkɪŋ	nephew or niece, a man's ZS or ZD
N08	kundung	kundʊŋ	sun
N09	kokok	kokok	elder brother (EB)
N10	kunkun	kunkun	on the right
N11	kunyangki	kunʝʊŋɡɪ	a long time ago
N12	mimbunje	mimbʊŋɛ	blind
N13	mandjad	mənʝəd	straight
N14	kanan	kenen	looking at
N15	kabanj	kepeŋ	it stinks!
N16	bebmeng	pɛpɪmɛŋ	to emerge
N17	bidnakenwong	pɪtnəkɛnwɔŋ	hand over to someone
N18	birndu	pɪŋdʊ	mosquito
N19	bongdi	pɔŋdɪ	live in difficulty
N20	borndok	pɔŋdɔk	spear thrower, woomera
N21	dangbalhmeng	tɛŋbəlʔmɛŋ	shut your mouth!
N22	mandedjmad	mɛndɛʝmɛd	the roots of a plant
N23	djendek	ʝɛndɛk	Sand Palm (<i>Livistonia humilis</i>)
N24	kundjenkeh	kunʝɛnkɛʔ	bird's nest

Continued on next page

Table B.2 Continued from previous page

ID	WORD	PHONETIC	GLOSS
N25	bilidombu	pɪlɪdombu	putting out a fire
N26	kanjdji	kɛŋɟɪ	Jabiru Stork (<i>Xenorhynchus asiaticus</i>)
N27	kebngakmeng	kɛŋɛkɛmɛŋ	drowned
N28	komdukan	komdʊkən	carry on the shoulder
N29	ngalmangiyi	ŋɛlmɛŋɟɪ	long necked turtle (various sp.)
N30	kunburrk	kunburrk	body (whole)
N31	kundjud	kunɟud	nape, back of the neck
N32	kundulk	kundʊlk	tree
N33	kunkurlba	kunkurlbe	black plum (<i>Antidesma ghaesembila?</i>)
N34	kunngabek	kunŋɛbek	hair (of the head)
N35	lambalk	lɛmbɛlk	sugar glider (<i>Petaurus breviceps</i>)
N36	lonbom	lonbom	wounded something
N37	manbarndarr	mɛnbɛŋderr	Turkey bush (<i>Calytrix exstipulata</i>)
N38	mandjad	mɛŋɛd	right way
N39	kunmud	kunmʊd	feathers
N40	njamkimuk	ŋɛmkɪmʊk	big belly (guts)
N41	ngudjmak	ŋɔɟmɛk	young (strong, powerful)
N42	njudmeng	ɲutmɛŋ	blow your nose! (imperative)
N43	kunnjurd	kunɲʊɾ	snot
N44	rlobmeng	lobmɛŋ/lobmɛŋ	run/drive

Continued on next page

Table B.2 Continued from previous page

ID	WORD	PHONETIC	GLOSS
N45	welengkenh	welɛŋkɛnʔ	our/yourself
N46	mandjimdjim	mɛŋʝɪmʝɪm	fresh water pandanus (<i>Pandanus aquaticus</i>)
N47	kinga	kɪŋɐ	Estuarine Crocodile (<i>Croodylus porosus</i>)
N48	yakminj	jɛkmɪŋ	finished, all gone
N49	woknang	woknɛŋ	said goodbye
N50	nang	nɛŋ	looked at/saw
N51	kakan	kɛkɛn	he's taking it
N52	kunmim	kunmɪm	eye
N53	mang	mɛŋ	I will get you
N54	kinhkinh	kɪnʔkɪnʔ	stars
N55	kang	kɛŋ	break open
N56	djang	ʝɛŋ	dreaming
N57	bangkerreng	pɛŋkɛɹɛŋ	late wet season, 'knockem-downs'
N58	kundulk	kundulɔk	stick (same as tree)
N59	kunrdurddu	kunʔutʔu	heart
N60	djenj	ʝɛŋ	fish (general)
N61	kundjud	kunʝud	nape, back of the neck
N62	kunkuk	kunkuk	body
N63	kunburn	kunbuŋ	ankle
N64	kundad	kundɛd	leg (thigh)
N65	kunbard	kunbɛʔ	knee
N66	ngadjadj	ŋɛʝɛʝ	mother's brother

Continued on next page

Table B.2 Continued from previous page

ID	WORD	PHONETIC	GLOSS
N67	kunmak	kunmek	good
N68	nang	neŋ	looked at/saw
N69	njale	ɲele	what?
N70	ngalngale	ŋelŋele	who is that woman?
N71	mangh	meŋ?	I will get you!
N72	nganomeng	ŋenomɛŋ	-
N73	karnubirr	kɛŋubirr	fresh water mussel
N74	kanjok	kɛŋok	wife, brother-in-law
N75	kangokme	kɛŋokme	carry away
N76	dengemok	dɛŋemok	step on s.t.
N77	mamam	memem	mother's father (MFZ,MF,DD,DS)
N78	karrowen	kɛrowen	-
N79	nawern	nɛwɛŋ	lots, many
N80	djenj	ɟɛŋ	fish
N81	birriweng	pɪrɪwɛŋ	they threw it away
N82	narangem	nɛrɛŋɛm	brother
N83	karndayh	kɛŋdeɟ?	large red kangaroo (female) (<i>Macropus antilopinus</i>)
N84	yiman	jɪmɛn	just like
N86	kunney	kunneɟ	elbow
N87	kunnjam	kunɲɛm	guts intestines
N88	kunngad	kunɲed	-
N89	kunmalng	kunmɛlŋ	soul (s.t. that survives physical death)

Continued on next page

Table B.2 Continued from previous page

ID	WORD	PHONETIC	GLOSS
N90	mankabo	mənkebo	water course, creek
N91	marnbom	mənɓom	made
N92	ngalyangdoh	ŋəlɟɛŋdoʔ	-
N93	kunngabek	kunŋɛbek	hair of the head
N94	manmanjmak	mənmeɟmek	good food (taste)
			Concluded