/s/	baisse avouée	baie savourée	pèssavoumé
	indécence innée	indécent ciné	andésenciner
	résidence indiquée	les résidants syndiqués	bésidancindiquo
	importance ultime	important sultan	euportensultème
	lisse allée	lit salé	lissaler
	lisse olive	lit solide	lissolite
	russe abordée	rue sabordée	ruçaborter

Tongue Body constriction differences in click types

Amanda Miller, Levi Namaseb and Khalil Iskarous

Abstract
We investigate the articulatory bases of the Back Vowel Constraint (BVC), where post-alveolar clicks pattern with uvulars and epiglottals in retracting and lowering [i], while palatal and dental clicks pattern with coronals and labials in occurring freely with [i]. Click production is thought to involve a velaric airstream mechanism, with the back edge of the cavity formed by a velar constriction. However, if all clicks have a velar posterior constriction, there is no explanation for their different patterning. We investigate the posterior constriction location (CL) of *palatal* and *post-alveolar* clicks. The posterior CL is measured relative to the shadow of the jaw bone in ultrasound images. Results show that the posterior CL for the post-alveolar and palatal clicks are in the uvular and pharyngeal regions respectively. Posterior constriction differences between clicks are the articulatory basis for the BVC, with the motivation being at the motor control level. The palatal click and [i] share the same agonist-antagonist pair of muscles, posterior genioglossus and hyoglossus, and can thus be easily sequenced. Conversely, the post-alveolar click involves a uvular posterior constriction involving styloglossus and anterior genioglossus muscles. The BVC is a phonological consequence of the difficulty of co-producing segments involving incompatible muscular systems.

1. Introduction

The Back Vowel Constraint (BVC) (Traill 1985) is the only known synchronic phonological pattern that provides insight into the phonology of place of articulation in click consonants. The constraint classifies one group of sounds that co-occur freely with high front vowels (coronal and labial pulmonic consonants, dental and palatal clicks), and another class of sounds that is blocked from occurring with high front vowels (post-alveolar clicks and uvularized and epiglottalized consonants)(Miller-Ockhuizen 2003, Miller 2006). However, the classes can not be easily differentiated by place of articulation, given that all clicks have been analyzed as having a velar posterior place of articulation based on tongue tracings from X-ray data (Traill 1985: 110; Ladefoged and Traill 1984: 19; Ladefoged and

Traill 1994: 36). In this paper, we undertake ultrasound investigation of the posterior constriction location in palatal and post-alveolar clicks for one speaker of Khoekhoe (the second author).

In Khoekhoe [əi] and [i] are phonemically contrastive. There is, however, a large frequency effect, with [əi] being much more frequent following post-alveolar clicks, and [i] being much more frequent following coronal pulmonic consonants and dental and palatal clicks. Similarly, [i] is extremely infrequent following post-alveolar clicks, and [əi] is infrequent following the dental and palatal click types. Velar consonant initial roots display similar frequencies of each vowel type. Table 1 displays the frequencies of initial consonant type with the two vowel phones under investigation in words in the Khoekhoe lexicon as captured in Haacke and Eiseb's (2002) dictionary. The table includes monosyllabic, bisyllabic and trisyllabic monomorphemic words. Native speakers, including our second author, view words containing post-alveolar click consonants and [i] as less good words (in the sense of Frisch and Zawaydeh 1997). The lexical frequency patterns display tendencies that are bidirectional. That is, dorsal pulmonic consonants (velars and uvulars) and post-alveolar clicks display higher frequency roots containing [əi], while coronal pulmonic consonants, and the palatal click type, are in roots with more frequent [i] patterns. It is also interesting to note that laryngeal consonant initials occur more frequently with [əi] than [i]. This is of interest because of the variability of laryngeals in lowering vowels, discussed in Rose (1996). This frequency effect mirrors stronger allophonic relationships between [i] and [əi] in related Khoisan languages Ju|'hoansi (Miller-Ockhuizen 2000; 203) and !Xóõ (Traill 1985, 1994, 1997; Miller-Ockhuizen 2000).

Table 1. Lexical frequency of words from Haacke and Eiseb (2002) containing [əi] and [i] in Khoekhoe according to initial consonant place

	[əi]	[i]
Labial pulmonic consonants	49	**75**
Coronal pulmonic consonants	25	**100**
Dorsal pulmonic consonants	**81**	7
Corono-dorsal (palatal clicks)	19	**42**
Corono-dorsal (post-alveolar clicks)	**195**	31
Uvular	**10**	0
Laryngeal	**27**	13

The different patterns that palatal and post-alveolar clicks display lack a phonetic explanation, given our current understanding of the production of clicks as all involving similar velar posterior constrictions. This understanding comes from Traill's (1985) and Ladefoged and Traill's (1984, 1994) X-ray tracings taken at the moment prior to the anterior release in all five !Xóõ click types. Thomas-Vilakati's (1999) electropalatographic study of the Bantu language IsiZulu clicks, however, shows that the posterior constriction location in the alveolar click type is post-velar, since no rear contact is shown on the pseudo-palate in the production of this click type. Palatograms of Khoekhoe velar pulmonic stops, palatal clicks and post-alveolar clicks provided in Beach (1938: Figures 6, 14 and 19) show that there is more front contact in the posterior constriction in the two clicks than in the velar pulmonic stop. Static palatography does not allow us to identify at which point in the posterior closure and release this more forward point of articulation occurs.

In this study, we investigate the articulatory bases of the BVC in Khoe and San languages by investigating posterior constriction location (CL) differences of the palatal and post-alveolar click types in Khoekhoe through ultrasound imaging of the tongue body and root. Khoekhoe is a good choice of language because [i] and [əi] are contrastive vowel phonemes, and thus we are able to investigate the articulation of the clicks in the two different vowel contexts. Additionally, our second author was in North America, making it easier to undertake an ultrasound study. More specifically, we test the hypothesis that the Khoekhoe central post-alveolar click type displays a uvular posterior gesture, contra the traditional understanding of all clicks as involving the velaric airstream mechanism. We report on the articulation of a single male speaker's productions of the palatal and post-alveolar clicks in the [əi] and [i] vowel contexts in Khoe-khoe.

In our study we focus on the posterior CL at the frame prior to release of the posterior constriction. This is a novel approach, as the only dynamic articulatory study of a Khoesan language has focused on the place of the posterior constriction at the onset of the click closure and at the moment prior to release of the anterior constriction (Ladefoged and Traill 1994). The moment in time prior to the release of the anterior constriction is critical because it is this time which defines the volume of the cavity between the two constrictions, which in turn determines the acoustic resonance relevant to the click burst. The greater cavity volume in the post-alveolar click results in a lower frequency click burst than found in the palatal click, which has a shallower cavity (Kagaya 1978; Traill 1985; Sands 1991; Ladefoged and Traill 1994; Ladefoged and Maddieson 1996). However, the releases of clicks are quite dynamic, and given that the posterior constriction is always released last (although we have seen some overlap in the two constriction releases for the palatal click), the dynamics of the posterior release are the most relevant to coproduction with the following vowel.

2. Methods

Five repetitions of the wordlist provided in Appendix A were recorded in two laboratories. The first experiment was undertaken at Haskins Laboratories, using an Aloka ultrasound machine, with a 3.5-5 MHz probe. The second experiment was undertaken in the Cornell Phonetics Lab using a GE Logiqbook ultrasound machine and a 5-8 MHz probe, with the output being channeled through a Micro T-view adapater, and acquired in Adobe Premiere Pro on a Dell Inspiron 8600 laptop. Sound was recorded using a Shure SM10A head-mounted microphone which was filtered through a pre-amplifier. Sound and video were mixed by an ADC video converter. Video was acquired at the sampling rate of 29.97 KHz, and audio was sampled at a rate of 32000 Hz with 16 bits per sample. In both experiments, the ultrasound probe was placed so that the jaw shadow was visible at the right edge of the image. The hyoid shadow moved quite considerably in the production of the palatal click and thus is not a stable landmark.

The video frame associated with the first glottal pulse of the vowel was identified as the frame encompassing the release of the posterior constriction in the click. Subsequent visual inspection of the dynamic tongue movement identified the peak constriction just prior to release. The peak [i] gesture was identified as the most anterior constriction in the palatal region associated with [i].

Sixteen repetitions of each click type (five repetitions of each word in Appendix A) were recorded in two vowel contexts, [i] and [əi]. Six repetitions of the words in Part A were recorded at Haskins Laboratories using their ultrasound setup. Five repetitions of the words listed in Part II of Appendix A were recorded at the Cornell Phonetics Laboratory, leading to sixteen repetitions of the two vowel types in each of the two vowel contexts. To quantify the position of the posterior click constriction in each token, we measured the angle from the first point of the constriction to the shadow of the jaw. The greater the angle seen, the more posterior the constriction is.

3. Results

Figure 1 provides typical images of the tongue shapes viewed in the ultrasound images at the frame just prior to the release of the posterior constriction location in the palatal and post-alveolar click types. As can be seen, the posterior constriction location of the post-alveolar click type is forward of the posterior constriction location associated with the palatal click type. The head is facing rightward as is the default for ultrasound images. The posterior constriction for the post-alveolar clicks is judged to be uvular, since that constriction is about 4-5 centimeters behind the palatal constriction for the vowel /i/, which is a location usually around the bend of the vocal tract. The posterior constriction location of the palatal click type is judged to be pharyngeal, since it is 6-7 mm behind the palatal constriction for the vowel [i], which is a location usually in the pharynx. Results show that the posterior constriction location of the two click types is post-velar, not velar, as was found by Traill (1985) and Ladefoged and Traill (1984, 1994). Dynamically, the posterior constriction for the post-alveolar clicks is achieved by retracting and raising the tongue dorsum and the entire tongue root in the uvular region, while that for the palatal click is achieved by retracting the upper portion of the tongue root.

Quantitative results capturing the angle from the ultrasound probe to the posterior constriction location in two vowel contexts are provided in Fig. 2. Again, we can clearly see that the posterior constriction location (CL) of the palatal click type is further back than the posterior CL of the post-alveolar click type.

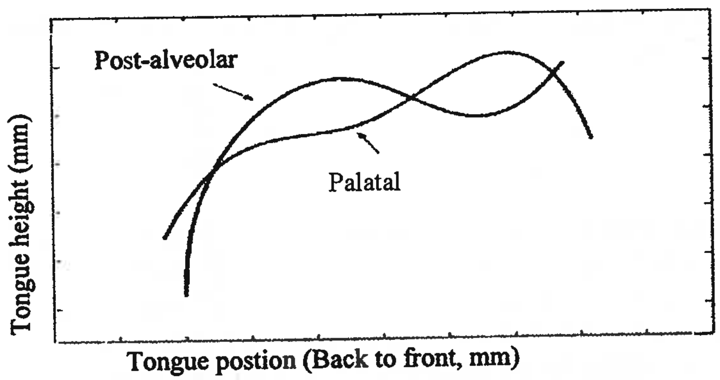

Figure 1. Posterior constriction locations of palatal and post-alveolar click types

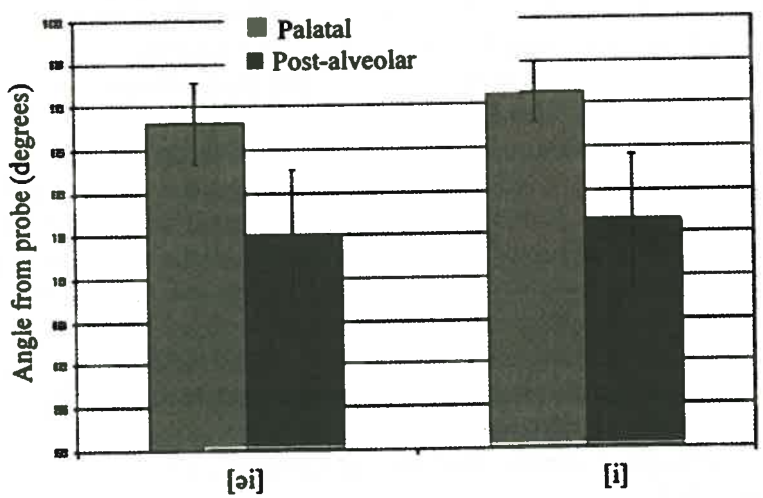

Figure 2. Angle from probe to posterior constriction location in palatal and post-alveolar click types

Given that this measure is relative to the ultrasound probe, which is not held steady through a transducer support system, it is necessary to ascertain whether movement of the probe could be skewing the results. Figure 3 provides a measure of the location of the [i] gesture relative to the jaw shadow, both of which are found in all stimuli. Results show that there is no significant difference between the location of the [i] gesture relative to the jaw for the two click types, which suggests that there was relative cnsistency in the location of the probe in the two click contexts.

The further back posterior constriction location for the palatal click type is a surprising result, although it agrees with Thomas-Vilakati's findings given that one would expect the click with the pharyngeal posterior constriction (the palatal click type) to display more retraction of a front vowel than the click with the uvular posterior constriction location (the post-alveolar click type). The posterior CL results show clearly that the CL in and of itself can not explain the phonetic bases of the BVC in Khoe and San languages, given that phonologically uvulars and pharyngeals usually behave as a class.

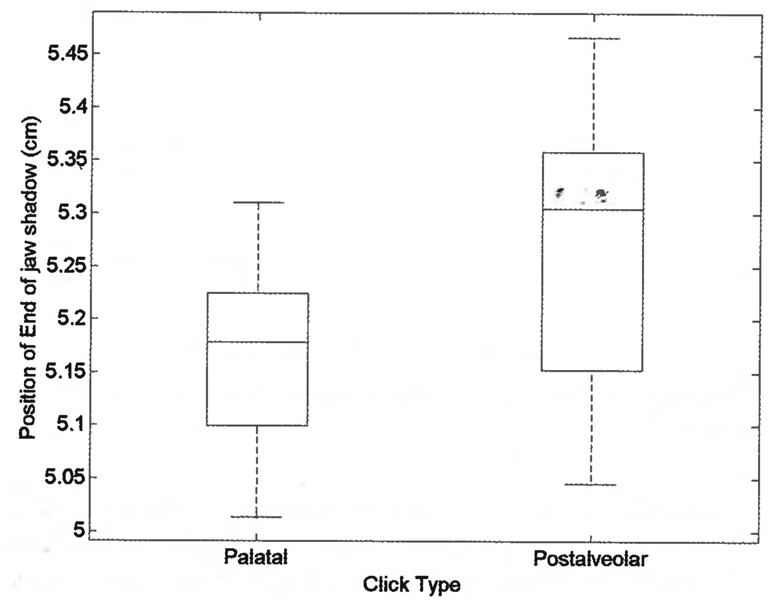

Figure 3. Position of [i] gesture relative to the jaw shadow

However, we have already seen that the palatal click type does not behave phonologically as a [pharyngeal] sound with regards to BVC patterns in Khoekhoe (see Table I). Khoekhoe patterns mirror the phonological patterns found in Ju|'hoansi (Miller-Ockhuizen 2003), N|uu (Miller, 2006) and !Xóõ (Traill 1985, 1994a,b, 1997).

Additional differences in the shape of the [i] provide evidence supporting an account for the physiological basis of the BVC at the motor control level. As seen in Figure 4, in Khoekhoe, the palatal click and [i] overlap, whereas the post-alveolar click and [i] do not. Figure 4a shows three frames from the beginning, middle and end of a palatal click-[i] sequence and Figure 4b shows three frames from a post-alveolar click-[i] sequence. As can be seen, the tongue root is more retracted and the tongue bòdy is lower for the [i] in the post-alveolar click context.

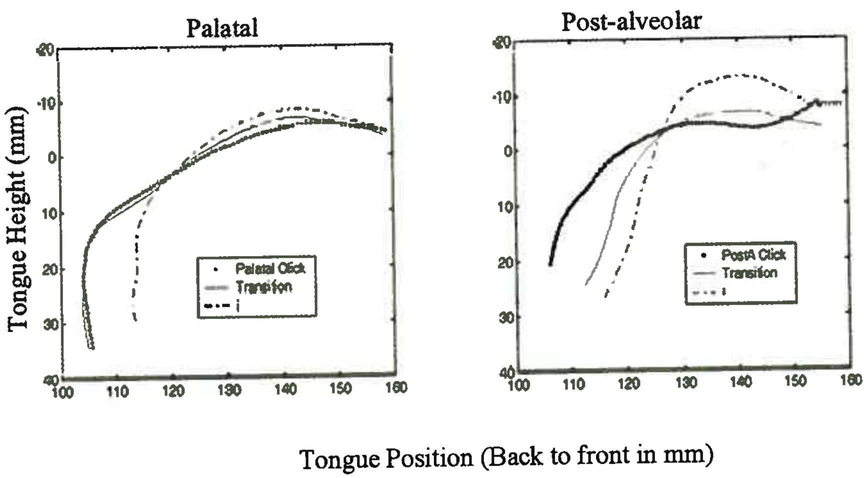

Figure 4. Transition from moment prior to posterior release of the click to the [i] gesture

Fig. 5 shows the average times between the release of the posterior constriction (dotted line above in Figure 4) and the [i] peaks (dashed lines in Figure 4) for four CVs: Palatal-[i], Post-alveolar-[i], Palatal-[əi], and Post-alveolar-[əi]. The palatal-[i] takes about 50 ms less to perform than the post-alveolar-[i] (of course this durational difference may appear to be greater than it is due to the low 30 Hz sampling rate).

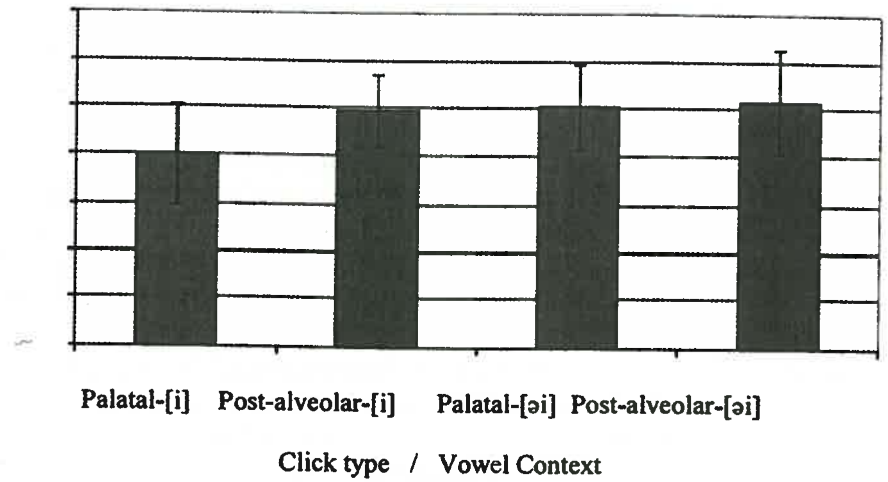

Figure 5. Duration from posterior release of the click to the peak tongue body

4. Discussion

The BVC governs the co-occurrence of clicks and the vowel [i]: the post-alveolar click is incompatible with [i], while the palatal click is compatible with it. The anterior constriction difference between the clicks is unlikely to be the reason for the constraint, since the anterior constriction of the post-alveolar click is performed with the tongue tip-blade, which can be functionally decoupled from the tongue body (as in palatalized [l]). Additionally, the tongue tip gestures are not relevant to the uvularized and uvular clicks that participate in the BVC in languages like N|uu and !Xõõ.

If the posterior constrictions of both clicks were in the velar region, as previously thought, the BVC would be surprising, since the two clicks would be expected to interact equivalently with the vowel. Our ultrasound study has shown that the post-alveolar and palatal clicks differ in the location of the posterior constriction. We propose that this articulatory difference is related to the BVC, since the posterior constrictions of the clicks make different demands on the tongue body, which is also used in the production of [i]. This articulatory conflict, we shall argue, is the basis of the constraint.

To understand the physical basis for the BVC, it is necessary to refer to the motor control of the body of the tongue. Four extrinsic muscles govern the motion of the tongue body: Posterior GenioGlossus (PG), Hyoglossus (HG), Styloglossus (SG), and Anterior Genioglossus (AG) (Zemlin 1968; Honda 1996). PG pulls the tongue root towards the anterior of the jaw, consequently advancing and raising the body due to the hydrostatic nature of the tongue (Stone 1990), whereas HG pulls the body downwards and backwards pushing the tongue root backward. SG pulls the body upward and backward, whereas AG pulls it downward and forward. PG and HG therefore act as one agonist-antagonist pair and SG-AG as another, both controlling the position of the tongue body (Honda 1996). The formation and release of gestures for different segments are controlled by both sets of agonist-antagonist pairs.

The main muscular activity for the vowel [i] comes from PG, which raises the tongue body upwards and forwards into the palatal position (Hardcastle 1976). There is no EMG data on Khoekhoe clicks (or clicks in any other language), but it is likely that the main muscular activity for the pharyngeal constriction of the palatal click is due to HG activity and that the uvular constriction in the post-alveolar click is due to SG activity. We can surmise this from the movement of the shadow of the hyoid bone seen in the ultrasound images of the palatal click type. The raised position of the hyoid suggests that the entire body of the tongue is raised upward and forward, and braced against the palate. The activity for a CV consisting of a palatal click and an [i], therefore, uses the PG-HG agonist-antagonist pair only, whereas for a CV consisting of a post-alveolar click and an [i], both sets of agonist-antagonist pairs, PG-HG and SG-AG must be used. But the two agonist-antagonist sets control the same object, the tongue body, and do so in orthogonal directions (Honda, 1996). If both sets act simultaneously, they would counteract each other's action. Therefore, for the post-alveolar-[i] sequence, the two sets of muscular controls cannot be used simultaneously, i.e. the SG-AG pair is activated after the PG-HG has finished its action. This contrasts with the palatal click-[i] sequence which uses only the PG-HG pair. Coproduction is possible only in the palatal click-[i] case, and is not possible in the post-alveolar click-[i] case. The BVC is therefore a phonological consequence of the desire for coproduction of the elements of a CV. Both the different shapes of the tongue in the [i] in the different click contexts seen in Figure 4, and the differences in the time it takes to realize the [i], evident in Figure 5, support this motor control level account of the physiological basis of the BVC.

5. Conclusion

This study has shown that there is a physiological basis of the BVC in Khoe and San languages. This difference is explained in terms of muscle compatibilities / incompatibilities. Furthermore, we have shown that the notion of the velaric airstream mechanism is too simplistic, since neither of the clicks studied involve a simple velar posterior constriction. The posterior releases of both clicks involve retraction into the post-velar region. We therefore propose that the term lingual airstream mechanism should be used instead. Ultrasound imaging is a valuable tool for investigating post-velar articulations, that were not able to be seen in fieldwork investigations of these sounds previously. Ultrasound imaging allows us to see dynamic tongue patterns in click posterior releases that account for the BVC, that could not be understood from static palatography / linguagraphy.

6. Future research

There are still additional click types that would need to be examined in order to determine if the physiological bases of the BVC holds true of all of the sounds that pattern together in the BVC. For example, this study did not investigate the dental click, which patterns like the palatal click, being compatible with [i], or the lateral post-alveolar click type, which behaves differently in different languages (and is probably tied to the articulation of the click in those languages), or a second type of lateral click found in Mangetti Dune !Xung (Miller-Ockhuizen and Sands 2000) nor did it investigate the labial click found in N|uu or !Xóõ, or the retroflex click found in Ekoka !Kung (König and Heine 2001).[1] Given that only one speaker is included in this study, it is not possible to determine which of these patterns are consistently present across all speakers, and which might show intra-speaker variation. Future research will investigate the articulation of these two click types, as well as dental and lateral post-alveolar click types for multiple speakers. Future research will also investigate the production of !Xóõ clicks, in order to reconcile the results presented here with the earlier X-ray results provided in Traill (1985) and Ladefoged and Traill (1984, 1994).

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Notes

1. !Kung is used rather than !Xung based on the orthographic decisions made by the Khoe and San council at the Penduka conference.

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Appendix A. Wordlist

Part I. Haskins Laboratories (6 repetitions each)

	Khoekhoe Orthography	IPA transcription	English gloss
1.	ǂgai	[ǂə̀í]	'to call'
2.	ǂgiǂgos	[ǂ̀ìí]	'politics'
3.	!gai	[!ə́í]	'to kick'
4.	!gii	[g!̀ìì]	'to be embarrassed'

Part II. Cornell Phonetics Lab (5 repetitions each)

1.	ǂgai	[ǂə̀í]	'to call'
2.	ǂgiǂgos	[ǂ̀ìí]	'politics'
3.	!gai	[!ə́í]	'to kick'
4.	!gii	[g!̀ìì]	'to be embarrassed'
5.	ǂgai	[gǂə̏ì]	'turtle'
6.	ǂgii	[gǂ̀ìí]	'blind'
7.	!gai	[g!ə̏ì]	'to bewitch; burp'
8.	!gî	[g!̀ìì]	'to lean against'

Temporal structure and the nature of syllable-level timing patterns: Comments on Arvaniti and Garding, D'Imperio et al., Fougeron, and Miller, Namaseb, and Iskarous

Kenneth de Jong

1. Introduction

The papers in this section deal with three different areas of inquiry; Miller, Namaseb, and Iskarous investigate factors underlying allophonic variation in understudied languages with understudied phonetic segments, Arvaniti and Garding, and D'Imperio et al. investigate tonal alignment in different prosodic systems, and Fougeron investigates syllabic and word parsing mechanisms. What all these have in common is a concern for understanding some aspect of the temporal structure of speech productions. The fact that such different studies deal with temporal structure illustrates both how pervasive a problem articulatory timing is in understanding a large variety of phonetic questions, and how little has actually been satisfactorily explained in the area of timing.

At the outset, we need to distinguish between temporal structures at three very different time scales, roughly (though not exactly) corresponding to what Hans Tillmann once called in a NATO ASI lecture, A, B, and C Prosodies. The shortest is patterning occurring at such a high rate that it is encountered as perceptions of qualitative differences in phonetic events. The longest is patterning at intervals of on the order of 1 second in duration, and it is encountered in terms of the sequencing of complex events. Literature dealing in this scale includes typological work on the 'stress-timed' and 'syllable-timed' distinction, work on tempo modulation, and prosodic relationships with syntactic parsing. Between these extremes are temporal structures which mediate between the qualities of individual events at the smallest levels of discernability and the higher-order alignment of utterances with lexical, pragmatic, and syntactic structures. At this intermediate level, the individual phonetic qualities comprise a complex dynamic composite of identifiable phonetic events, and it is the