

Research Statement

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Overview

My research focuses on the physical properties (phonetics), and distributional patterns (phonology) of multiply articulated segments and the relationship between their physical properties and cognitive patterns. Speech segments are minimally contrastive units that make up words. They can be articulated with a single articulation, or with multiple articulations. Multiply articulated segments include speech sounds that have two simultaneous labial or lingual constrictions, as well as sounds that have sequences of articulations within a single segment. I am particularly interested in the mapping of individual articulatory gestures, which capture the movement of single articulators, to higher-level articulatory / acoustic goals. I have proposed two such goal-oriented areas of higher-level sound structure: tongue shape, and airstream. Spurred on by my desire to view sub-segmental timing relations in multiply articulated segments, I have developed a new high-speed ultrasound method called CHAUSA (Corrected High-speed anchored ultrasound with software alignment), which allows me to view the phasing of gestures in multiply articulated segments at intervals of 8 ms and higher. I have also elicited and transcribed lexical data from endangered Khoesan languages, and created lexical databases that allow me to discover and document phonological patterns in these languages. My phonetic and phonological studies are undertaken in concert, such that my phonetic investigations serve the role of identifying the phonetic bases of the phonological patterns that I uncover. I focus on problems that, based on our current understanding, seem to defy a straight-forward mapping between phonetics and phonology. Detailed analyses of novel phonetic and phonological data collected through my own fieldwork lead to a simpler mapping between the two levels of sound structure.

Complex and Contour Segments

There are two main types of multiply articulated stops: *complex segments*, which are single sounds that have two constrictions that are nearly simultaneous; and *contour segments*, which are single sounds that are sequences of articulations (Sagey 1990). I study the two main types of complex segments: clicks and labial-velars. Additionally, I have discovered a new type of contour segment, the *airstream contour*. This research serves my goal of placing segments that are viewed as linguistic oddities into the realm of complicated sounds that are predicted to occur by current models of speech articulation. My analyses of clicks have led to the extension of theories in natural ways.

Clicks

Much of my research has focused on click consonants. My research on clicks provides multiple examples of how my phonetic analyses lead to reanalyses of sounds and sound patterns. The analyses, in turn, lead to more straight-forward mappings between phonetics and phonology. Clicks are complex segments. Figure 1 provides a diagram showing the basic stages of click production, and labels the various parts of the palate and posterior tongue used in click production.

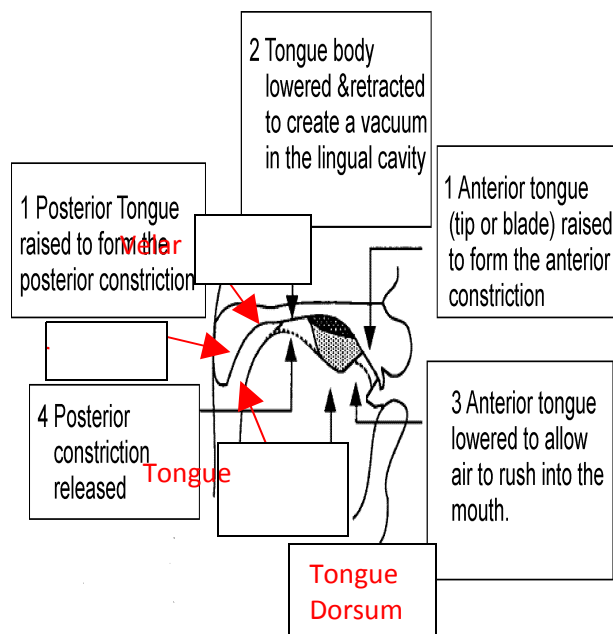


Figure 1. Model of Click Production based on Ladefoged and Traill (1994)

Clicks are produced with two constrictions (one in the anterior part of the mouth, and one in the posterior part of the mouth) that overlap temporally, and that are claimed to be simultaneous phonologically. In clicks, the tongue is used to create a negative pressure cavity between the anterior and posterior constrictions, and the anterior release initiates the ingressive flow of air. Suction is created in the lingual cavity formed by the tongue, and air is rarefied in this cavity as the anterior tongue is released, which creates the characteristic popping sound found in clicks. Clicks can thus be described as having rarefaction gestures, which capture the movement of articulators that results in the rarefaction of air within the cavity formed by the tongue.

The Back Vowel Constraint (BVC) is a co-occurrence constraint found between clicks and front vowels, as well as other segments and front vowels. However, earlier research focused only on the basic clicks, ignoring the rest of the sound inventories of the languages that contain clicks in their inventories. The results was that there was previously no workable account of the BVC that also accounted for the patterning of the non-click sounds, and more complex click releases. I have shown, via ultrasound data, that palatal clicks have a back uvular constriction that involves tongue root raising, while the central alveolar clicks have a front uvular posterior constriction that involves tongue root retraction (Miller, Namaseb and Iskarous 2007, Miller, Scott, Sands and Shah 2009). That is, different clicks have different tongue root shapes, and the different shapes account for the different phonological patterns seen in the BVC. The articulatory data on clicks shows that there are different types of uvulars, and that not all uvulars involve tongue root retraction as suggested by McCarthy (1994) and Rose (1996). Further, the presence of tongue root retraction in the production of alveolar clicks makes the posterior constrictions in these clicks more like uvular sounds found in Semitic and Salishan languages. Tongue root retraction is not a matter of constriction location or place of articulation, but rather it is a matter of tongue root shape. Thus, the click data relies on tongue shape to allow a straightforward mapping between phonetic and phonological components of the grammar. My analysis sees the BVC as a cross-linguistically common pattern of vowel retraction following uvular segments. Thus, clicks are subject to cross-linguistically common patterns that are understood once we understand their physical phonetic properties.

Miller, Scott, Sands and Shah (2009) have shown, via high-speed ultrasound data collected using the CHAUSA method, that the rarefaction gestures in the four Mangetti Dune !Xung coronal clicks differ greatly. Mangetti Dune !Xung is an endangered Ju-#Hoanⁱ language spoken in Namibia, that has never been the subject of phonetic or phonological studies. Figure 2 provides five traces of each of the clicks, and two traces in the following /i/ vowel, which is subject to allophonic variation. The phonetic realization of /i/ following the alveolar and lateral clicks is [əi] in all Khoesan languages described as having the Back Vowel Constraint. Contrary to our current understanding of the BVC, this speaker of Mangetti Dune !Xung also produces [əi] following the palatal click. In each of the graphs, the fifth trace is the ultrasound frame of the tongue just prior to the release of the anterior constriction, and we know that the posterior constriction is also in place at this time. Thus, by viewing the cavity formed by the tongue between the two constrictions in traces 1 through 5, we can see that each of the clicks uses a different rarefaction gesture. The dental and palatal clicks involve almost solely tongue center lowering, while the alveolar click involves tongue dorsum and root retraction as well as tongue center lowering, to create the suction that makes the loud click sounds. The lateral click involves a narrowing of both constrictions to lengthen the cavity. Further, the [i] vowels following the clicks show a high degree of co-articulation, with the vowel following the palatal click maintaining two constrictions right until the peak palatal gesture in the [i].

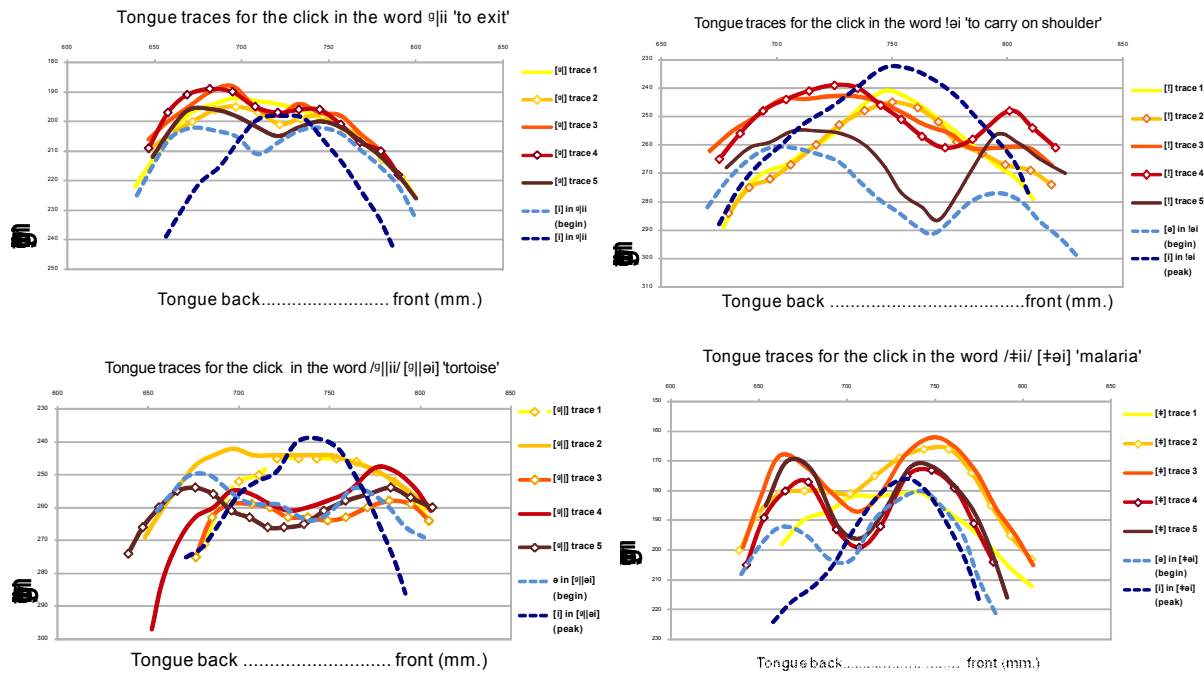


Figure 2. Five sagittal tongue traces during the production of the click, the first frame in the [i] vowel following the click release, and the peak palatal gesture in the target vowel in the words ǀji 'to exit' (upper left), ǀsi 'to carry' (upper right), ǀǀəi 'tortoise' (lower left), and /ǀii/, [ǀəi] 'malaria' (lower right).

These data provide evidence for the hydro-static nature of the tongue (Kier and Smith 1985; Levine et al. 2005), and show that there is a large degree of co-articulation between clicks and following front vowels, and thus debunks the claim that clicks don't co-articulate (Dogil, Mayer and Roux 1996). Again, we see that clicks follow behaviors that have been found with non-click segments.

High-speed ultrasound studies of the tongue during the production of the IsiXhosa and Mangetti Dune !Xung alveolar clicks, provides evidence for the mass-spring model of the tongue used in Task Dynamics (Saltzman 1986). As seen in Figure 3, the tongue tip lowers completely during the release, then recoils to a mid height position, before lowering again, and rising up for the following high vowel [i]. This kind of recoil effect has never before been seen in studies of speech, though it was predicted to occur by models of speech production.

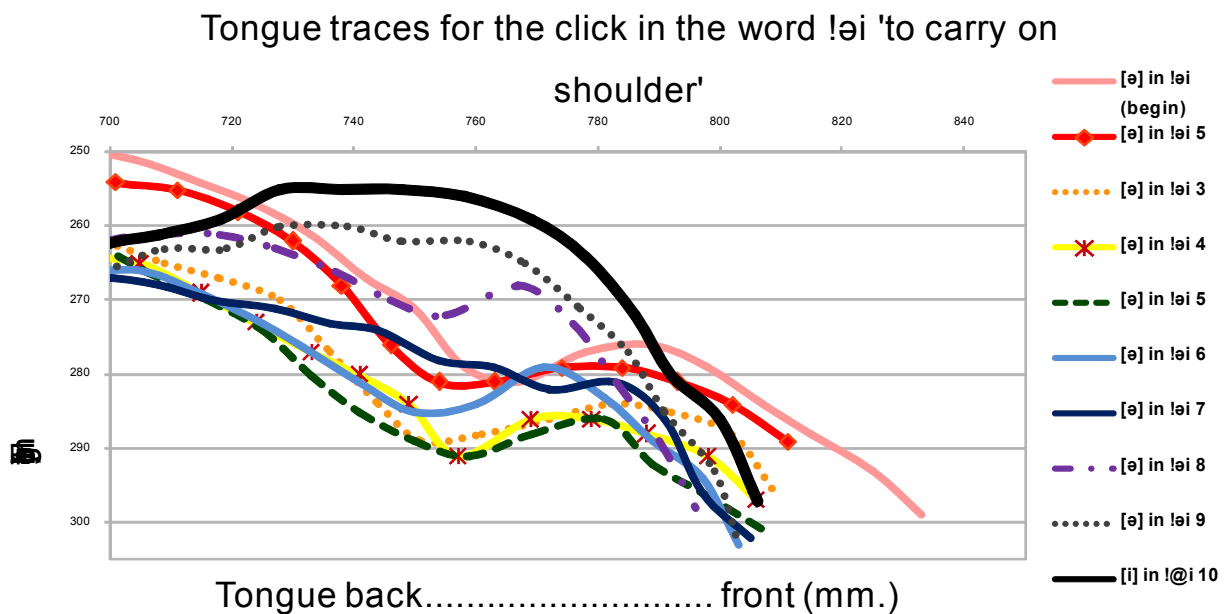


Figure 3. First ten sagittal tongue traces in the vowel following the Alveolar [!] click in the word !əi 'to carry' in Mangetti Dune !Xung

Labial-velar stops

Labial-velar stops are the other main type of complex segments described by Sagey (1990). I am currently studying Dagbani labial-velars. Dagbani data are of particular interest because labial-velars front to labial-coronals in front vowel contexts in the language. This study will be the first phonetic description of labial-coronals, as Ladefoged and Maddieson (1996) note that they had not been able to document the existence of these sounds though they had been reported in Dagbani by Ladefoged (1964). The main goal of this project is to investigate the tongue dorsum retraction that occurs as part of the velar release in these sounds, and to investigate whether tongue root retraction goes hand in hand with tongue dorsum retraction. My hypothesis is that tongue dorsum and tongue root retraction are incompatible with following front vowels, much in

the same way that tongue dorsum and tongue root retraction found in the alveolar click in N|uu and Mangetti Dune !Xung is incompatible with following front vowels. The repair strategy undertaken for sequences of clicks and labial-velars with front vowels is different in the two cases. The Back Vowel Constraint in Khoesan languages is responsible for retraction of front vowels to the diphthong [əi] following alveolar clicks, while the constraint found in Dagbani is responsible for a fronted variant of the dorsal gesture in labial-velars in front vowel contexts.

Airstream Contour Segments

In addition to my research on tongue shape in complex segments, I have undertaken research investigating airstream contour segments. Contour segments are described by Sagey (1990) as involving a sequence of articulations within a segment. Known contour segments are affricates, which are contours in manner of articulation, and pre-nasalized stops, which are contours in nasality. I have proposed contour segments in airstream as a new type of segment (Miller et al. 2009, Miller 2009). N|uu contains a class of clicks similar to those termed *uvular* clicks in !Xóõ and †Hoan. Traill (1985), Ladefoged and Traill (1994) and Ladefoged and Maddieson (1996) describe the posterior place of articulation of these clicks as uvular, and as contrasting with the plain clicks, that have a so-called velar posterior place of articulation. My finding that plain clicks all have a uvular posterior place of articulation, and the phonological patterning of the so-called *velar clicks* similarly to the so-called *uvular clicks*, led me to question whether the so-called *uvular clicks* differed from the so-called *velar clicks* in terms of posterior place of articulation. My ultrasound studies (Miller et al. 2009, Miller 2009) have shown that the N|uu alveolar and palatal *velar clicks* do not differ in terms of posterior place of articulation from the alveolar and palatal *uvular clicks*. I propose that these clicks are airstream contour segments, which are lingual (velaric) airstream during the first part of the segment, and pulmonic airstream in the second part of the segment, much as affricates are contours in manner of articulation. The existence of such segments provides evidence that *airstream* is a fourth phonetic dimension that needs to be added to the standard three part description of consonants embodied in the International Phonetic Alphabet (Miller et al. 2009). That is, in addition to place of articulation, manner of articulation, and phonation, airstream must also be described.

Development of the CHAUSA Method

In order to investigate sub-segmental timing, I have developed a portable high-speed ultrasound method, which has allowed me to image Khoesanⁱⁱ speakers' tongues producing clicks in Namibia and South Africa at rates as high as 124 fps. This frame rate yields an image of the tongue every 8 ms, which is close to the rate that is used for some types of acoustic analyses. This development realizes the full potential of ultrasound to do for articulatory phonetics what the spectrograph has done for acoustic phonetics.

The CHAUSA method (Miller and Finch 2009) makes it possible to undertake high-speed articulatory and acoustic studies of complex and contour segments. Benefits in terms of increased speed, improved spatial clarity, to-the-frame Articulatory-to-Acoustic Alignment, Probe-to-head anchoring and Head Movement Correction are found with this method. While there are other high-speed methods becoming available, none is as good as CHAUSA, and

CHAUSA is the only high-speed portable method. The data coming out of the video port and VGA port of ultrasound machines has inherent distortion that has been documented by Wrench and Scobbie (2006). The CHAUSA method and architecture uses DICOM data transfer (the same data transfer protocol that your doctor uses to transmit x-rays and ultrasounds from the lab to his / her office). The DICOM protocol assures data with impeccable image quality. This data transfer method, along with the sharp image quality of the GE LogiqE machine at speeds of 124 fps, make detecting the tongue edge much simpler than with other architectures. The CHAUSA method is the only high-speed method that has near perfect articulatory-to-acoustic alignment at high speeds. This means that I am able to undertake simultaneous high quality acoustic and articulatory analyses that are not possible with any other articulatory apparatus used in speech. The combination of probe anchoring and head movement correction assures that all movement seen by the tongue in the ultrasound images is attributable to tongue movement, with none of it due to head or probe movement. The development of CHAUSA has been long and laborious, and much of my research time has been focused on methodology. The data collection methodology and associated analysis tools have now been fully developed, and will allow me to undertake quantitative analysis of articulatory data.

Linguistic Fieldwork on Endangered Languages

Phonetic Documentation

Doing fieldwork on endangered and undocumented languages is an important component of my research. I have documented the sounds of endangered Khoesan languages. Khoesan languages contain new sounds that are not currently recognized or included in the universal inventory of sounds that phonetic and phonological theories need to account for. These languages sound inventories are among the largest sound inventories in the world. My team has published a paper describing the entire inventory of N|uu segments (Miller et al. 2009). N|uu is a moribund language, and it is the only remaining member of a language sub-family that has never been documented. In a recent study, I have documented an apparently new type of click found in Grootfontein !Xung (Miller, Shah and Sands 2009) with high-speed ultrasound using the CHAUSA method, palatography / linguography, and acoustic measurements. This click is post-alveolar, and thus Grootfontein !Xung is the first language to exhibit an alveolar vs. post-alveolar click contrast, though alveolar vs. post-alveolar non-click consonant contrasts occur in a handful of languages. There is a great deal of variability found in the articulatory and acoustic realizations of this click for the three speakers studied, which suggests further study is needed for definitiveness. We have reflected that the variability found is due to the central location of Grootfontein !Xung within the !Xung dialect continuum. The click is of interest because Sands (forth.) has posited it as the modern day reflex of a proto-retroflex click. By studying all modern day reflexes of the proto-retroflex click, we expect to gain more insight into the articulatory and acoustic properties of the proto-sound, which will enrich Sands' model of click change.

Phonological Documentation

Description and analysis of phonotactic patterns in Khoesan languages is an important part of my work. While phonetic studies often serve to show the phonetic bases of phonological

patterns, the inverse is also true. Namely, the description and analysis of phonological patterns points to areas where the phonetic description of sounds seem out of place, and make the mapping between phonetics and phonology seem more complicated than necessary. I have elicited large amounts of lexical data from the Khoesan languages Ju|'hoansi and N|uu using a combination of traditional linguistic field methods and more high-tech methods. I have created lexical databases for each of these languages, coded the databases with binary specifications for multiple levels of sound contrast found in these languages, and mined the databases to document the phonology of the languages. Since the morphology is largely isolating in the Ju - †Hoan and Taa language families, the phonology is largely realized in the form of co-occurrence restrictions. My dissertation (Miller-Ockhuizen 2003) reported the findings of a database study in Ju|'hoansi, and documented a new Guttural consonant-vowel co-occurrence restriction. In Ju|'hoansi, there is a large number of guttural consonants and vowels (sounds produced in the throat). It is striking, that words containing guttural consonants (aspirated, glottalized, uvularized and epiglottalized consonants), never co-occur with guttural vowels (breathy, glottalized and epiglottalized vowels). This study also documents the Back Vowel Constraint found in Ju|'hoansi, and multiple other co-occurrence restrictions. Miller (2009) reports on the Back Vowel Constraint (BVC) in N|uu. The N|uu BVC provides data as to the patterning of the so-called *uvular clicks* found in several Khoesan languages. The patterns show that the so-called *velar clicks* pattern the same as the so-called *uvular clicks*, suggesting that the posterior place of articulation among these clicks do not differ. The documentation of the patterns involving these sounds is important since they are found in less than 5 living Khoesan languages, and all of these languages are highly endangered.

Phonetic and Phonological Model

My research takes the findings of my detailed phonetic and phonological analyses, and relates them to models of sound structure. While I aim to simplify the mapping between phonetics and phonology, I do not shy away from complex mappings where they are justified. I have developed a phonetic and phonological model of clicks, which contains gestures that characterize movement of individual articulators (e.g. tongue tip, tongue body, tongue root) and their shapes, in the phonetic component; as well as a higher-level articulatory / acoustic goals component in the phonology. The model contains an upper-level representation for *tongue shape* and *airstream*. As noted by Abercrombie (1967:24), *airstream* crucially 'makes audible the movement of other organs'. Without an airstream, there would be no sound. In spite of this truism, most models of speech sounds currently do not represent airstream, due to the complexity of the mapping from articulatory gestures to articulatory /acoustic goals. The model of clicks in Miller (2009) argues that airstream provides evidence for the higher-level goals model of articulation, as lingual airstream is produced through an intricate phasing of the anterior and posterior gestures of clicks along with the ingressive and egressive flow of air. I propose the term *lingual airstream* to replace *velaric airstream* (Miller, Namaseb and Iskarous 2007; Miller et al. 2009), because the posterior constriction in clicks is not velar, and the anatomical source of the air is not the velum. The name *lingual airstream* reflects the anatomical source of the airflow.

The model proposes tongue shape at a higher level of control, while maintaining individual articulatory gestures at the lower level. This represents tongue root retraction as part of the goal of tongue root shape, similar to the tongue shape parameters included for tongue tip (Browman and Goldstein 1989) and tongue body (Miller, Namaseb and Iskarous 2007) embodied in Articulatory Phonology.

Future Research

I am currently visualizing high-speed lingual ultrasound data for complex segments, and performing statistical tests of Smoothing Spline Analysis of Variance for four separate parts of the tongue to determine how many different shapes are used for each part of the tongue in complex segments. In the second stage of analysis, I will perform Principal Components Analysis to determine if there are correlations between the shapes of the four parts of the tongue. I will use these data to determine how many parts of the tongue should be used in physical and cognitive models of speech, and develop a cognitive model for complex segments. In the third stage, I will work with computer science researchers to model the production of clicks in a 3D articulatory model of speech production called *Artisynth*. Studying complex segments that involve intricate tongue postures in African languages will make great strides towards building more universal physical and cognitive models of speech production. Complex and contour segments such as clicks, labial-velars and airstream contours are a good test-bed for Stone et al.'s (2004) claim that there are five functional tongue segments. Their claim is based on English data, and I expect that speakers of African languages with clicks and labial-velars may use more functional tongue segments than are typically used by English speakers. I plan to make detailed comparisons between labial clicks and labial-velars; between coronal-uvular segments such as [t̪χ] and [c̪χ] that occur in Khoesan languages and dental, alveolar and palatal clicks; and between the velar lateral obstruent [k'] and the lateral click [||] in ꞤHoan. These statistical data will inform linguistic phonetic models of sounds, as they will provide data showing how many parts of the tongue need to be modeled to capture all and only the contrastive segments found in languages. By studying multiply articulated segments with some of the most complex tongue shapes found in the world, the model will take the first step towards building a more universal model. I also plan to investigate the predictability of different tongue segment positions and shapes in sequences of segments to investigate models of co-articulation. Namely, I will investigate the tongue shape in vowels following clicks and labial-velar stops, to see if it is predictable from the tongue shapes found in the preceding consonants.

The combination of investigations of complex and contour segments found in African languages and a unique high-speed method that allows simultaneous articulatory and acoustic studies allows me to make ground-breaking phonetic analyses of sounds that we were unable to view with previous research. These data allow me to make observations and analyses that bring new insights to models of sound structure, and allow a more straight-forward mapping between the phonetic and phonological components of grammar. My intricate and intertwined phonetic and phonological analyses allow us to see sounds that were previously viewed as oddities as complex, but rule-governed.

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ⁱ Ju-#Hoan is the name proposed by Güldemann 2006 for the language family. It largely replaces the Northern Khoisan family, but also recognizes the closer affiliation of #Hoan to the languages formerly known as Northern Khoisan languages.

ⁱⁱ Though the spelling *Khoisan* is prevalent in the academic literature, the communities that speak these languages prefer *Khoesan* because it more closely represents the spelling in their orthographies. Note also that we use *Khoesan* throughout as a cover term for languages from several unrelated southern African families with similar segment inventories and phonotactic patterns, but few if any established inter-family relationships. See Güldemann and Vossen (2000) for discussion.