The role of the glottic and epiglottic planes in the phonetic qualities of voice in the Bor Dinka language (Sudan) and other phonetic features: a laryngoscopic study

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1. Introduction. The source-filter theory of speech production assumes that speech output in humans results from a source of sound energy (the larynx) coupled to a resonance filter whose transfer function is determined by the geometry of the supralaryngeal airspace. This account ultimately goes back to work by Johannes Müller 1848, who attached excised human larynges to blacksmiths' bellows and discovered that sounds thus produced were quite unlike those of humans until tubes of appropriate length were attached to the tops, cf. the account of speech production in the website //www.haskins.yale.edu/haskins/HEADS/MMSP/acoustic.html/. Many investigators since have explored the shapes, lengths, and constrictions of these tubes. Indeed, through this powerful and predictive model much has been learned. That said though, speech production in many of the world's languages cannot be adequately analogized to a child blowing with pursed lips into a toilet roll. Instead, initiating speech is much more like pressing vibrating lips to a trumpet blowing first into a shaping and constricting mouthpiece. Thus, events on the **glottic plane** (the trumpeters lips) are followed by other dynamic events on the **epiglottic plane** (the mouthpiece of the instrument) before the shaped and appropriately throttled wave can enter the pharynx, a three-term and not a two-term process. One of the languages that shows the influence of glottic and epiglottic planes is the Moinyjieng language (more commonly called Dinka) of Sudan. It is thus appropriate that the empirical part of this investigation is devoted to the transnasal fiberoptic laryngoscopic (tfl) study of the special qualities of voice that are a part of the linguistic system of Moinyjieng. We also include a description of other phonetic features of the language such as vowel qualities and more details of consonant articulation.[1] In the description below we will present our results in a form familiar to all from television where runners' and jumpers' muscle configurations are analyzed in terms of still figures taken frame-by-frame from the video capture, in order to show the stages in the

[1] The first four authors are listed in alphabetic order. Deborah Martin arranged the informant help and provided important linguistic data in the construction of the word list of contrasts. Jerry Edmondson provided financial support to the informants and did a lot of the preliminary writing. John Esling and Jimmy Harris were crucial in refining the paper and for important theoretical insights.. Dr. Ed Weisberger MD and Lesa Blackhurst were instrumental in providing superb endoscopic services for the experiments and provided very helpful contributions to physiological and anatomical issues in this paper. The authors wish to acknowledge the assistance of Bishop Nathaniel Garang, Reverend Bartholomay Bol, Margaret Kuol of Arlington, Texas, and Mr. Abui Deng, who were at the time of the experiment 65, 39, about 40, and 22 years of age respectively. They have all signed a letter of informed consent that allows us to thank them for their help publicly.

preparation, execution, and aftermath of sprints or jumps. This is also the technique of choice and the one employed here to show the remarkable and very rapidly transpiring gestures on the glottic and epiglottic planes used by Moinyjieng speakers in executing the voice quality contrasts found in their language. Indeed, it is the rapidity of movements, darkness in the lower throat, and the lack of imaging equipment near to speakers that have prevented the study of such phenomena until now. We will be claiming that Moinyjieng has four distinctive voice qualities, which we will notate under the vowel as follows: *modal voice* v (no mark), *breathy voice* v̤ (subscripted umlaut), *tense voice* v̲ (underline), and *hollow voice* v̼ (subscripted gull wing).

Moinyjieng (Dinka) has been the subject to study and to attempts at reducing it to writing for a relatively long time. Roettger and Roettger 1989 say that literacy efforts for Dinka began in the "early 1900s". These labors were culminated in an important conference in 1928 attended by missionaries, government officials, and a linguistic advisor, the noted Africanist, D. Westermann.. Churchmen after this time continued important work on the language, such as Father P. Nebel, who brought out his *Dinka Grammar* in 1948 and his *Dinka-English, English-Dinka Dictionary* in 1954. Scholars and government officials continued this work. Notable is the survey of varieties by Britishers Tucker and Bryan 1956, who ascertained that Dinka had 24 varieties within four subtypes. Perhaps the first native-speaker linguist to write about Dinka was Job D. Malou, in his book, *The Dinka vowel system* 1988, where he talks about the *modal voice-breathy voice* contrast. Duerkson in 1989 published a paper on Dinka 'h' and in 1997 Dinka dialects. Larry and Lisa Roettger in 1989 confirmed the Tucker and Bryan divisions in their survey of phonological, lexical, and grammatical difference in Dinka. In his dissertation Keith Denning broke new ground suggesting four kinds of voice quality in Bor Dinka with fewer of these contrasts in other varieties of the language. Recent work includes Gilley 2003 has taken other tacks suggesting that stress is a significant feature of Dinka. Torben Anderson 1987 and 1993 in two important papers pled the case for three vowel lengths in Agar Dinka.

In order to put Bor Dinka in perspective of the language as a whole, we would note that the Ethnologue (www.ethnologue.com) reports there are five kinds of Moinyjieng: *Northeastern,* population 320,000, *Northwestern,* population 80,000, *South Central Dinka*, population 250,000, *Southeastern* or *Bor Dinka* also with a population of 250,000, and *Southwestern* or *Rek Dinka* with a population of 450,000. These numbers perhaps underestimate the total population, as the Britainnica Online www.britannica.com/eb/article?eu=31004 for 2002 give it as 4 million. Over the last 1-2 years we have had opportunity to examine the speech of more than 10 speakers of Bor Dinka, which is the focus of the study presented here.

The writing system used by the United Bible Society for Moinyjieng includes the graphs <a b c d dh e è g i j k l m n ng nh ny o ò p q r t th u w y> whereby the accented e and o represent open forms of these vowels, i.e. [ɛ ɔ]. The other five vowels are often changed when they appear in a particular voice quality. There are also breathy vowel recognized in this orthography, signified by a circumflex over the vowel in question and "centralized" vowels have two dots of the vowel in question. In this orthography the symbols with a following ‘h’ such as <th dh nh> are said to represent ‘dentalized’ consonants. The consonant ‘ny’ is a palatal nasal [ɲ].

In the Moinyjieng language most word forms have the shape CVC or CVVC; CV also occurs very frequently. As described by Duerksen (1989:125), Moinyjieng phonology has voiced and voiceless stops (including affricates) and nasals at five places of articulation as well as contrastive sounds **l, r, y,** and **w**. These sounds are with the orthographic system in Table 1.

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Table 1: Moinyjieng Orthographic Consonants

Stops	**p**	**th**	**t**	**c**	**k**
	b	**dh**	**d**	**j**	**g**
Nasals	**m**	**nh**	**n**	**ny**	**ng**
Laterals			**l**		
Trills			**r**		
Glides	**w**			**y**	

Consonants can also have secondary articulations of palatalization indicated by **y** or labialization indicated by **w**. Moreover, final consonants can be released or unreleased, but release is probably conditioned by syllable position, though it was felt to be significant enough to warrant including release or its lack in Roettger and Roettger’s survey data. We provide in the next paragraph a phonetic description corresponding to each consonant graph in Table 1 from our study of several Bor Dinka native speakers.

The graph **p** represents a voiceless aspirated bilabial oral stop [pʰ]. The graph **b** represents a voiced bilabial imposive [ɓ]. The graph **m** represents a voiced bilabial nasal [m]. The **t** is a voiceless apico-alveolar oral stop [tʰ], which contrasts to the sound represented by the graph **th**, which is a voiceless aspirated apico-dental lamino-alveolar (denti-alveolar) oral stop [t̪̻ʰ] or a voiceless denti-alveolar affricate [t̪̻ᶿʰ]. Another less common variant is a voiceless denti-alveolar oral spread (flat) fricative [θ̪̻]. The graph **dh** represents a voiced apico-dental lamino-alveolar oral stop [θ̪̻] or voiced denti-alveolar [d̪ð̻] and can sometimes vary to a voiced denti-alveolar fricative [ð̪̻]. The graph **d** is a voiced apico-postalveolar implosive [ᶑ]. In word final position it has two variants. The most word-final variant in normal everyday conversation is a voiceless glottalized apico-alvealar stop, which is a voiceless apico-alveolar stop plus a simultaneous glottal stop [ʔ͡t]. The graph **nh** is a voiced apico-dental lamino-alveolar (denti-alveolar) nasal [n̪̻], which is in contrast with **n**, a voiced apico-aleovar nsal [n̺]. Phonologically, we could state that dental stops and nasals **th**, **dh**, and **nh** contrast with alveolar stops and nasals, **t**, **d**, and **n**, which is not very common in languages of the world. The graph **l** is a voiced apico-alveolar lateral [l]; **r** represents two variant r-sounds: a voiced apico-alveolar trill [r] and a less common voiced apico-alveolar tap (flap) [ɾ]. The graph **c** is a voiceless slightly aspirated advanced fronto-palatal (prepalato-palatal) affricate with a short narrow grooved fricative release [cç^{h}]. The graph **j** represents a voiced advanced froto-palatal (prepalato-palatal) affricate with a short narrow grooved fricative release [ɟʑ̟]. The sequence **ny** stands for an advanced fronto-palatal nasal [ɲ̟] and **y** is a voiced fronto-palatal approximant [j], which occurs initially and intervocalically. The symbol **k** is a voiceless aspirated dorso-velar oral stop [k^{h}]. The graph g is a voiced dorso-velar oral stop initially and intervocalically; finally in careful overly correct speech, it is a voiced dorso-velar oral stop with a short schwa offglide release [gə]. In normal conversational style speech the final **g** is a voiceless unreleased glottalized dorso-velar stop, which is a voiceless dorso-velar stop plus a simultaneous glottal stop [ʔ͡k]. The nasal **ng** is a voiced dorso-velar nasal [ŋ]. The orthographic **q** is an important clue in the Dinka phonological story. There is widespread variation in pronunciation of this segment. Often it is a voiceless glottal fricative [h] and at other times it is a voiced dorso-velar fricative [ɣ] or voiced glottal fricative [ɦ], or nothing at all, cf. the discussion below. This sound does not occur before high vowels or turns them in diphthongs.

Although we have transcribed the orthographic **p**, **t**, **k**, and **c** as aspirates, aspiration is at best a marginal feature of the voiceless stops and affricates, which means that in initial position they can have more or less VOT depending upon the voice quality of the syllable. Aspirated voiceless stops and affricates tend to show less aspiration when the syllable has tense voice, whereas breathy voice engenders more aspiration. Duerksen (1989:120) says, “Before Breathy vowels there is a stronger aspiration but before Non-Breathy vowels the aspiration may not even occur.” Also, [h], a voiceless glottal fricative is a phonetic feature that only occurs before utterance initial vowels, but not before semivowels or consonants. If the syllable is breathy, the initial [h] will be voiced.

In support of the claim that orthographic **b** and **d** are imploded, consider Figure 1 below, which shows and airflow wave (Rothenburg Mask, Glottal Enterprises, Inc.) taken from the speech of Ms. Margaret Kuol.

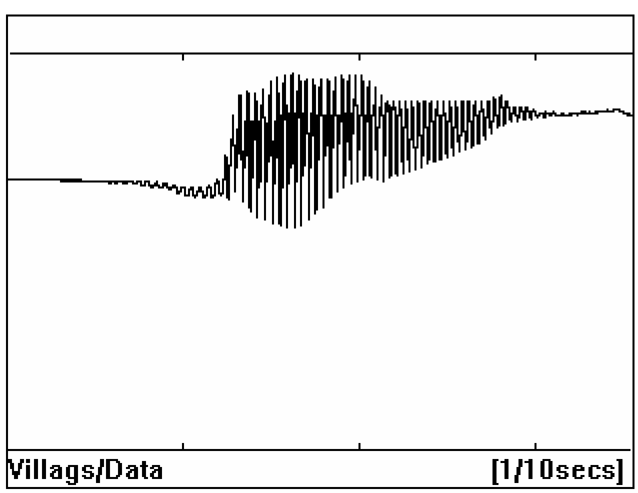


Figure 1: Airflow wave from ɓɐi̯^{44} ‘villages’

As can be clearly seen, the waveform descends from the base level while voicing and then abruptly rises at the release of the bilabial implosion.

Although the Moinyjieng word structures, as noted above, consist mostly of CVC monosyllables, this language differs dramatically from the monosyllabic languages of East and Southeast Asia by possessing a rich system of morphological alternations. Such morphological alternations are used to signal categories such as singular-plural-collective, movement toward or away from the speaker, etc. The morphology very frequently find expression either as *quantitative alternations* of the vowel such as long versus short vowels or *modulatory alternations* of the vowel such as modal versus breathy, tense versus modal voice quality, etc. It is also quite common to combine both quantitative and modulatory changes. Many of these changes are discussed by Anderson 1987 and 1993 and Duerksen 1989 and (pc), who describes three major types of vowel changes to an underlying five-vowel system of contrasts /i e a ɔ o/. Duerksen's rules are important clues that Dinka qualifies as a *register language* as described by Eugenie Henderson (1952) of a type we also found in Somali, Edmondson, Esling, and Harris (2003). Deborah Martin, in her field work, also became aware of the lockstep of voice quality, vowel quality, syllable duration, and possibly tone, and dubbed Moinyjieng a *chord-ish* language, meaning that there are phonologically recurring patterns in Moinyjieng that combine voice quality, vowel quality, syllable duration, and tone in "chords". A part of this system is seen in Table 2, which shows the connection of voice quality with vowel quality in our modification of Duerksen's rules.

Table 2: Moinyjieng morphological vowel changes

(1) Quantitative alternations of vowels—short and long vowels;
(2) Modulatory alternations such as

a. Non-breathy to breathy engenders: [i] -> [i̤], [e] -> [e̤], [a] -> [a̤], [ɔ] -> [o̤], and [o] -> [ṳ];

b. Non-tense to tense engenders: [i] -> [i̱ɛ̱], [e] -> [ɛ̱], [a] -> [ɛ̱], [ɔ] -> [a̱], [o] -> [u̱ɔ̱]; [ɛ] -> [a̱];

c. Non-lowered to Lowered when breathy engenders: [i̤] -> [iɛ̤], [e̤] -> [ɛ̤], [a̤] -> [ɛ̤], [o̤] -> [ɔ̤], [ɛ̤, ɔ̤] -> [a̤]

[ṳ] -> [ia̤] _ p, b, m
[uɔ̤] _ elsewhere

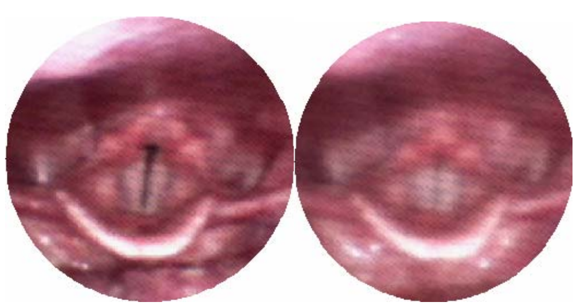
In addition there are also some morphological categories manifested by changes of consonants. For example, Father Nebel describes the *qualified nouns* of Moinyjieng, which are nouns followed by another noun, adjective, or possessive, e.g. the name *Moinyjieng*, the autonym, consists of *Moc+Jieng* people+people/tribesmen, in which *moc* [mɔcç] becomes a qualified noun form [mɔɲ]. For other consonants classes there are similar rules of homo-organic softening of stops to nasals, i.e. p -> m, t -> n, th -> nh, k -> ng.

In the orthographies developed by missionaries only two voice qualities have generally been distinguished, modal and breathy. These are usually indicated by no changes for modal vowel and by a circumflex accent or two dots over a breathy vowel. Denning 1989, chapter five, found in a study of one speaker of Dinka spoken at Bor with the technique of harmonic differential (spectral tilt) a contrast of four voice qualities.

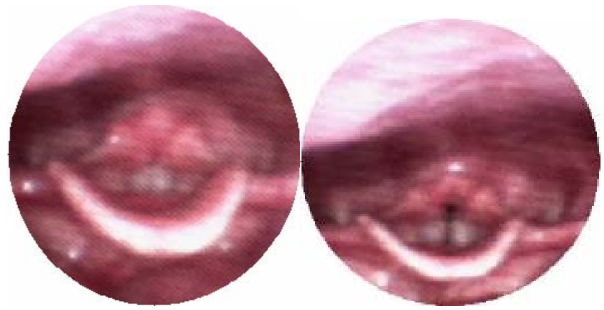
2. Methods. To study Moinyjieng voice qualities, three native speakers from Bor where examined with the technique of transnasal fiberoptic laryngoscopy (TFL). The equipment used in this experiment was the new Kay Elemetrics Digital Video Endoscopy/Stroboscopy System, for viewing and recording laryngeal anatomy and vocal fold physiology with direct digital video capture onto computer storage media. At a later time the video files were transferred to DVD's in AVI format for viewing and further processing. The procedure involved first numbing the subjects' nose openings slightly with an aerosol spray and then a small fiberoptic tube was inserted into one nostril and then guided into the area behind the tongue to a position that afforded a clear direct view of the aditus laryngis, epiglottis, aryepiglottic folds, and the larynx with glottal aperture. The subjects then repeated a list of words as prompted by the investigators while their performance of these words was being recorded in video and audio files. The wordlist was based on our study of Moinyjieng in an extensive session of data elicitation and high-quality audio recordings of Mr. Abui Deng the day before the TFL experiments; earlier trial data was gathered through elicitation and recording of Ms. Margaret Kuol of Arlington, TX by Edmondson. After the TFL experiments, the videos were examined frame-by-frame with the digital editing software Adobe Premier® to determine the configurations and positions of structures on the glottic plane, i.e. the glottal folds, ventricular folds and structures on the epiglottic plane, i.e.the supraglottal cavities (e.g. sphinctered aryepiglottic folds), epiglottis, and arytenoids cartilages.

In order to study the effects of voice quality on vowel quality, pitch plots, sound spectrograms, and power spectra (spectral tilt plots) of Mr. Deng and Ms. Kuol were also prepared.

3. Results. The video images of the three Moinyjieng informants confirm the claim of the late Keith Denning that Bor Dinka has four voice quality distinctions. We will call these four, mostly following him: (1) *breathy voice*, (2) *modal voice*, (3) *tense voice*, and (4) *hollow voice*. In Figures 2 and 3 we present still images from the videos and sound spectrograms of the four voice quality contrasts.

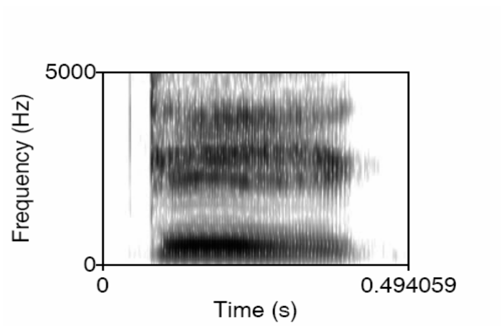


a. *tçi̤t̪*^{42} 'go ahead' breathy voice b. *tçi̪t̪*^{42} 'diarrhea' modal voice

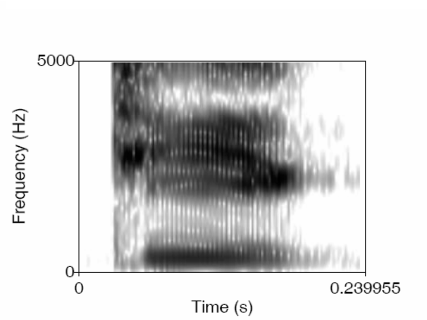


c. *tɕʲɛ̰t̰*^{42} ‘scorpions’ tense voice d. *tɕʲɛ̰̰t̰̰*^{42} ‘swallow’ hollow voice

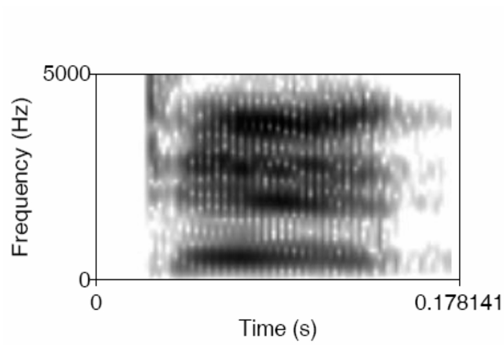
Figure 2: Frame captures of four voice qualities just after the mid-point of the syllable



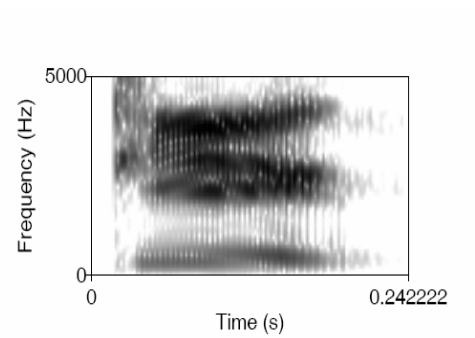
(a) *tʰi̤k*^{42} ‘action’ breathy voice



(b) *tʰik*^{42} ‘chin’ modal voice



(c) *tʰⁱɛ̰k*^{42} ‘divide’ tense voice



(d) *tʰⁱɛ̰̰k*^{42} ‘woman’ hollow voice

Figure 3: Sound spectrograms of Dinka Bor voice qualities

In Figure 2 and 3 one sees that voice quality differences can be analyzed along two planes: Figure 2 (a) and (b) have the glottic feature [±adducted glottal folds] and the epiglottic feature [-sphinctered a-e folds] and Figure 2 (c) and (d) have the glottic features settings [±adducted glottal folds] and the epiglottic plane [+sphinctered a-e folds]. In Figure 3 (a), *breathy voice* shows an expansion of the epiglottic sphincter in the posterior-anterior dimension, which results in weakly defined vowel formants at higher formants with energy roll-off with increasing frequency. Note that F2 and higher have very light tracings. Figure 3 (b) portrays modal voice, which has adducted glottal folds and non-sphinctered a-e folds; spectrally this voice quality has F1 and F2 of similar strength and clear striation of formant bars even at higher frequencies. In Figure 3 (c), tense voice has adducted glottal folds and sphinctered a-e folds. The formant pattern is dark and heavily striated. Finally in Figure 3 (d), Hollow voice has non-adducted glottal folds and sphinctered a-e folds. The first formant is broken (diphthongization) with strong higher formant profiles and somewhat lighter F1 definition.

There is also a correlation of voice quality and vowel quality. In Figure 4, we show the effects of voice quality on the high and low position of vowels for two speakers.

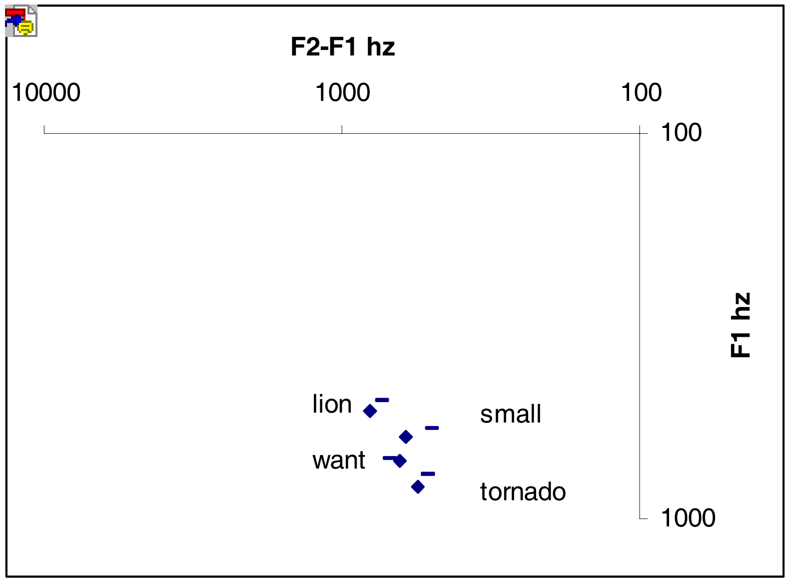


Figure 4: Vowel plot of two Bor speakers for [k^{h}ṳr^{44}] ‘lion’, [k^{h}or^{44}] ‘small’, [k^{h}ə̳r^{44}] ‘want’, and [kɔ̲r^{44}] ‘tornado’

4. Discussion. The Moinyjieng language shows a very rich inventory of voice quality contrasts rivaling the four contrasts in the Tibeto-Burman language Bai of Yunnan, cf. Edmondson et al 2000 and the four in the Mon-Khmer language Chong of Chantaburi Province Thailand and adjoining areas of Cambodia. The four contrasts in these voice quality languages differ in interesting ways. Not surprisingly, all have modal voice as one of the contrasts and all of them have breathy voice as a contrast, though the breathy voiced appears to differ among the three in the details. Moinyjieng has a form of tense voice that compares favorably to that of Bai. But unlike Bai, it has the patterns of voice quality-vowel quality interaction we found in Somali, cf. Figure 4 above and Edmondson et al 2003. In Somali the tense, sphinctered supraglottal cavity shape of the epiglottic plane produced vowels that were more retracted than the lax, expanded set. For that reason we adopted the designation *linguistic register* used by Henderson to describe Khmer vowels for Somali. We believe that the situation in Moinyjieng is quite similar. Breathy (with lax glottal settings) produces raised vowel, cf. Table 2 above, and Tense (with sphinctered supraglottal settings) produces lowered vowels. In fact, that there are two distinct sets of changes suggests that a least three voice quality settings are in play (Duerksen assumes only two—modal and breathy).

As Figure 1 shows, there are two planes at work: (1) the **glottic plane** and (2) the **epiglottic plane**. Both of these can be constricted, but the direction of the constrictions are mostly antiparallel. The adduction of the glottal folds is in a transverse direction whereas the constriction of the epiglottal plane is posterior-anterior. The two planes can be likened somewhat to the lips and mouthpiece of a trumpet (cf. Titze's Science for Singers).

Modal voice

Breathy voice

Tense voice

Hollow voice. Hollow voice in Moinyjieng represents a voice quality that at first blush might seem to involve a contradiction. The glottic plane requires settings: (1) abducted glottal folds and chink between the arytenoids (though not all speakers may demonstrate the degree of breathy settings seen in Figure 1(d) and (2) elevated pitch from rocking of the crico-thyroid muscles (extrinsic tension) into a low larynx posture. The epiglottic plane requires a sphinctered setting.

The voice quality of Moinyjieng in native speakers resemble very much a pathological muscle tension pattern described by Koufman et al 1995 under the name of *Bogart-Bacall-Syndrome*. It is not uncommon for distinctive non-pathological voice qualities in one language to be pathological in another.

Muscle Tension Pattern II (MTP II). MTP II is characterized by compression (medialward pressure) of the false vocal cords. In its mildest form, only the anterior portions of the false vocal cords are compressed--almost approximating, or actually touching together. (When the false vocal cords come into contact and are used for phonation, this produces a severe, pitch-locked dysphonia. False-cord voice, sometimes termed *plica ventricularis*, is a relatively common functional voice disorder.) Muscle Tension Pattern III (MTP III). MTP III is characterized by partial anteroposterior contraction of the larynx during phonation. Typically, the arytenoids are pulled forward toward the petiole of the epiglottis, obscuring the posterior one-half to two-thirds of the vocal folds. (MTP III is seen in patients who speak using a very low-pitched voice, the so-called "Bogart-Bacall syndrome." Also, it is routinely seen when singers sing the lowest note of the vocal range.). Muscle Tension Pattern IV (MTP IV) Extreme anteroposterior contraction, i.e., complete sphincter-like closure of the larynx, in which the arytenoids actually contact and squeeze against the petiole, is characteristic of MTP IV. (This pattern is uncommon, but it is seen in severe functional voice disorders and in patients with spasmodic dysphonia.)

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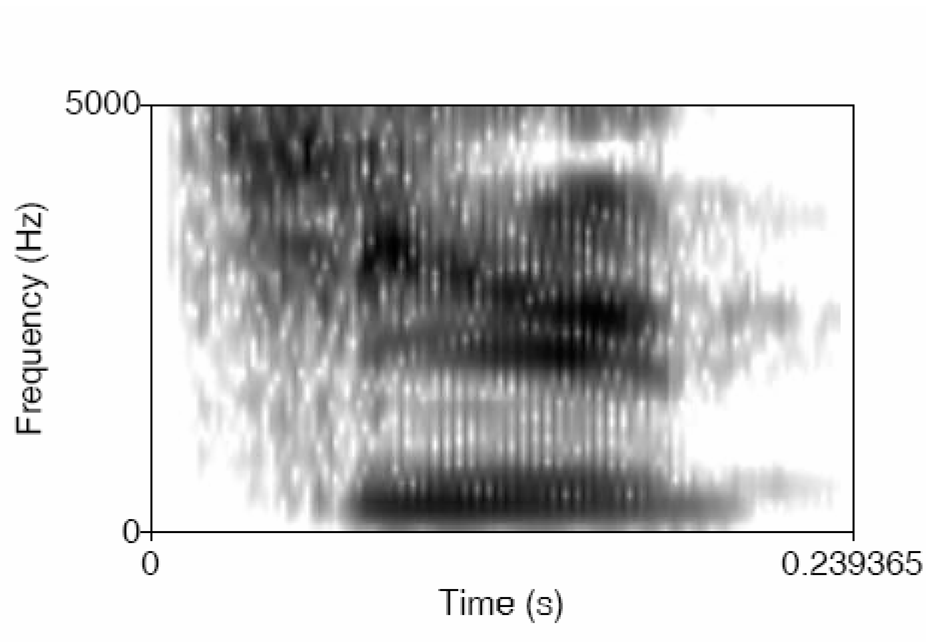
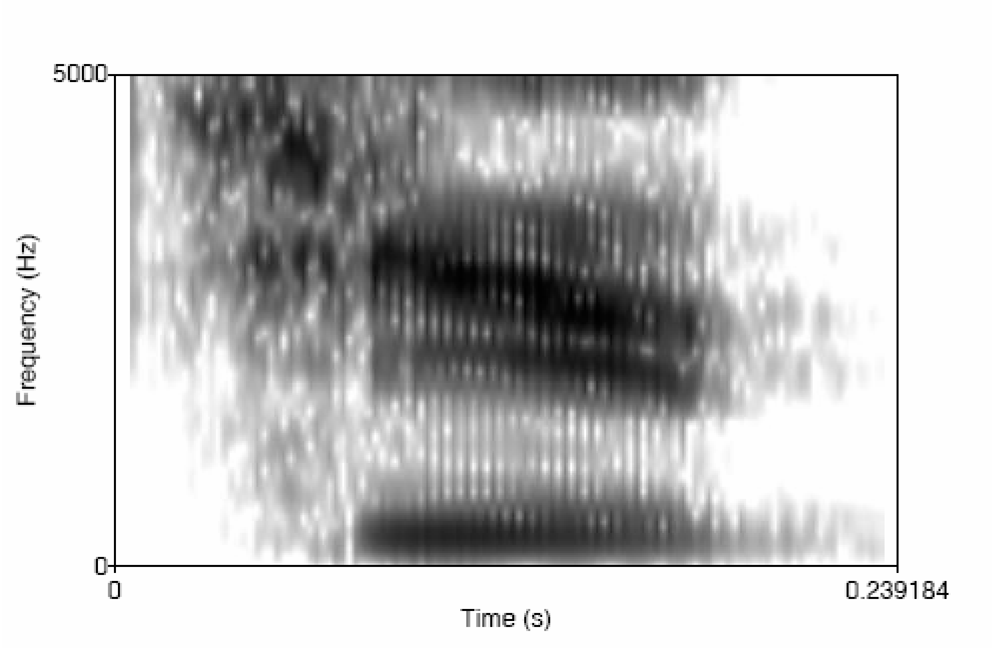
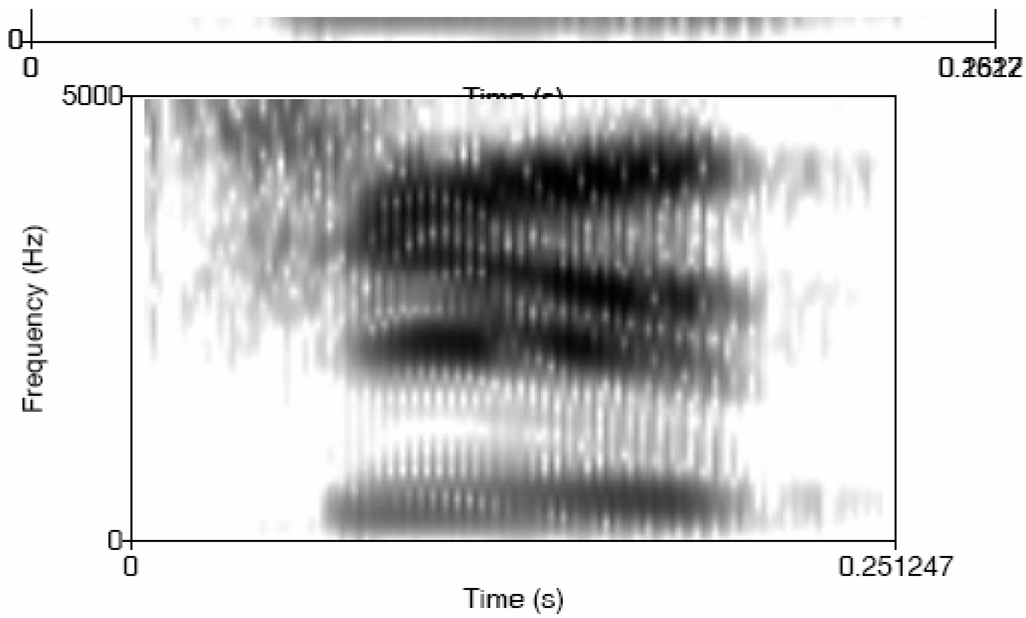


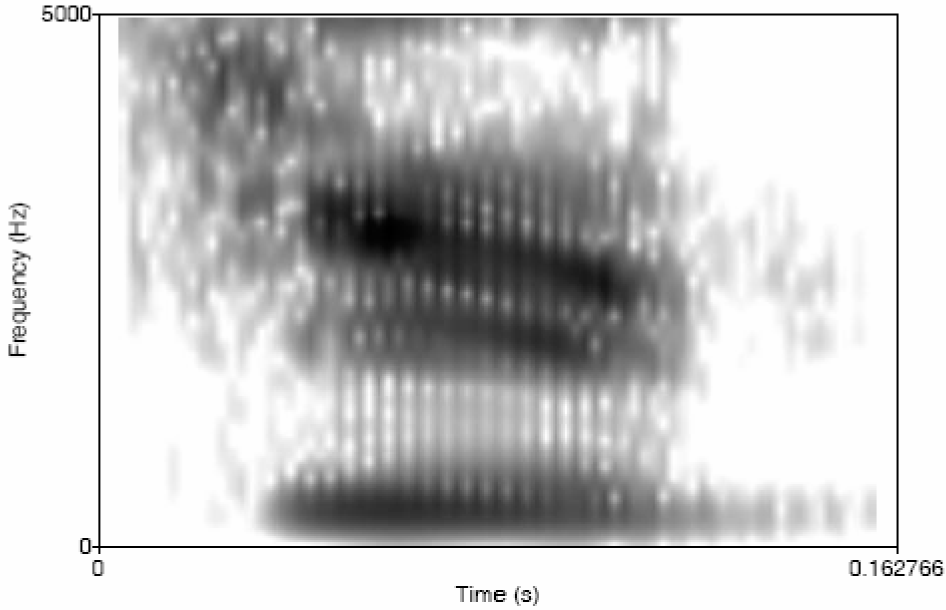
tc̤i̤t^{42} ‘go ahead’ breathy voice



tɕit̪^{42} ‘diarrhea’ modal voice



tɕʲɛ̱t̪^{42} ‘scorpions’ tense voice



tɕ^{i}*ɛ̰t̪*^{42} ‘swallow’ hollow voice