PHONOLOGICAL AND CONTEXTUAL FACTORS AFFECTING VOICE QUALITY IN DINKA VOWELS

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Abstract

Dinka language is Nilotic language with rich and complex suprasegmental and morphological system that has not been investigated fully yet. Furthermore, voice quality is a linguistic notion that is also understudied in its phonological and phonetic sense. This paper is concerned, primarily, with investigating the relationship between breathy voice with Dinka vowels and, secondarily, with whether there is an actual association between certain voice qualities and certain tonal patterns in Dinka language.

In order for this investigation to take place a large volume of Dinka utterances dataset is employed. Firstly, the data was quantified and, secondly, some appropriate scripts were utilized for the calculation and extraction of the desired values. The statistical analyses of the findings have showed that there are some strong correlations between certain voice qualities and tones as well as that some phonetic properties are more reliable as acoustic correlates of breathiness than others. In the end, this paper establishes a new understanding of the aforementioned goals and to some extend assesses the applicability of the scripts to other similar studies.

Declaration

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

Finally, the work conforms to the guidelines for presentation and style set out in the relevant documentation.

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Abbreviations

Abbreviation	Extension
1S	*First singular*
1SG	*First singular*
3S	*Third singular*
ADV	*Adverb*
ANTIP	*Antipassive*
DECL	*Declarative*
DECLS	*Declarative (Singular)*
DECLSG	*Declarative (Singular)*
DECLP	*Declarative (Plural)*
EXIST	*Existential predicate*
EXISTYNQ	*Yes/no question involving existential predicate*
IMP	*Imperative*
IMPER	*Imperative*
INTR	*Intransitive*
INF	*Infinitive*
LOC	*Locative*
LOCPRED	*Locative predicate*
MODIF	*Modifier*
N	*No number contrast*
NEG	*Negation*
NOMCOP	*Nominal predicate (using copula)*
NTS	*(having) Non topical subject*
OBJECTDIR	*Direct object*
OBJECTINDIR	*Indirect object*
P	*Plural*
PAST	*past-tense infinitive*
PET	*Centripetal*
PETAL	*Centripetal*
PL	*Plural*
PASS	*Passive*
PREP	*Preposition*
SEQ	*Sequential*
SG	*Singular*
VA	*Verb + Argument*
VERBFIN	*Finite verb*
VERBNF	*Infinite verb*
ZERO	*Basic inflection*

Contents

Chapter 1

The introduction

This paper constitutes the formal treatise which is required for the completion of the Master of Science in Speech and Language Processing. In this chapter, first the reader will be introduced to the principal notions that this dissertation is concerned about. Next, the main questions are going to be addressed as well as the ways that these questions will be attempted to be answered. Finally, an outline of this paper's structure is going to be provided so that the reader to be aware of what to expect next.

The predominant concepts that are going to be explored are voice quality and Dinka language. First of all, voice quality is generally related with various definitions depending on the scientific field that it is studied. Chiefly being a linguistic term, it could be defined as any oscillatory process of the parts of the larynx which modifies the airstream coming of the glottis under the scope of the linguistics sub-fields of phonetics and phonology. Another definition that could be given would be the points on a continuum of tension and closure of the vocal cords (Gordon, M., & Ladefoged, P., 2001). However, the apparent variety of the definitions as well as the difficulties in the practical examinations of voice qualities (for example laryngoscopic studies are often necessary for the investigation of voice qualities) have led voice quality to be one of the least investigated linguistic notions. Furthermore, very often voice quality is studied under the fields of speech pathology and vocal pedagogy which are involved mainly with speech impairments and communication disorders. Therefore, the linguistic examination of voice quality in relation with the languages around the world is often undervalued.

The second subject under examination is Dinka language. Dinka is a Nilotic dialect cluster which is spoken by the Dinka people, the major ethnic group of South Sudan which is particularly associated with cattle-herding. Dinka as a Nilotic language belongs to the Nilo-Saharan family, and as most of the languages that belong to this linguistic family, it has very little been investigated. Many reasons could contribute for that such as wars, famine, movements to refugee camps in search of food, medical attention, and safety, among others. Nevertheless, independently of the reasons why these languages lack examination, there are in contrary many reasons why they should be investigated and, among others, Dinka in particular. Dinka has a quite rich and complex phonological and morphological system that has not been studied in its full extent yet. Moreover, Dinka exhibits two or three voice qualities, depending on the dialect, which are contrastive to each other. Finally, in addition to voice qualities, Dinka has also three or four contrastive tonal patterns, again, depending on the dialect which combine freely with the voice qualities. Therefore, new knowledge about tonal languages could emerge by the investigation of Dinka.

It has already been shown that this paper is involved with matters that are still unresolved in a great extent. Additionally, the lack of well-established research on the topics of voice quality and Dinka language makes this study even more intriguing. Thus, the major investigation of this paper is basically focused on the relationship between voice quality and Dinka language and, to be more precise, on the association of breathy voice quality with Dinka vowels. Breathy voice is one of the contrastive voice qualities in Dinka. Therefore, emphasis is going to be given of how and to what extent breathy voice is correlated with Dinka vowels, more particularly, whether there is a way to predict the voice quality that a Dinka vowel carries based on some phonetic properties that are generally considered to be associated with breathy voice. Moreover, the reliability of these phonetic properties as acoustic correlates of breathy voice is going to be further studied. Finally, a secondary goal of this study is to investigate whether there are any correlations between a particular voice quality and a particular tonal pattern in Dinka.

The aim of this investigation is dual. On the one hand, the findings will hopefully provide us with new answers on breathy voice quality and broaden our knowledge on voice quality in general or at least concur with the existing studies on the same subject and confirm their findings. On the other hand, it will shed some new light on Dinka's phonological and possibly morphological system and extent our understanding of the structure of this understudied language, the function of breathy voice quality in Dinka language in particular. In order for this aim to be achieved, some computational methods are going to be employed. More specifically, the processing of the data, the calculation and the extraction of the target values that are required for this investigation in particular, is going to take place with the aid of scripts. These scripts are predominantly designed so that they automatically calculate the values of complex acoustic properties, such as spectral tilt, or of other more straightforward, such as duration, as well as to be applicable to a large dataset uniformly. The findings themselves will evaluate their efficiency and, as thus, whether they can be reused by other researchers for similar studies or not.

At last, after a brief introduction to the work of this paper, a description of the next chapters is given next. In Chapter 2 a concise and adequate presentation of the existing literature on the topics of voice quality and Dinka language will be given. In Chapter 3 the material and the procedure for the analysis of the data will be explained. In Chapter 4 the results of the investigation will be presented and analyzed. In Chapter 5 a discussion will follow upon the topics under study and the findings will be explored and discussed further. Finally, in Chapter 6 the conclusion of this study will be assessed. The aim of this structure is to provide an adequate and self-contained package of knowledge to the reader and render them able to comprehend the investigation of this paper.

Chapter 2

The theoretical background

This paper is concerned with two major topics; voice quality and Dinka language. In this chapter, firstly, an adequate presentation regarding the major studies on voice quality, breathy voice in particular, as well as the phonetic correlates and measures related to it will be provided and, secondly, a self-contained description of the basic characteristics of Dinka phonology and morphology will be given.

2.1 Voice quality

Phonation or (loosely) voice quality is generally defined as the production of sound by the vibrations of the vocal folds, independently of prosody, emotion, speaker identity or any clinical pathology. Although most commonly defined in terms of speech impairments and disorders, voice quality is one of the aspects of speech that is still less-studied and needs further investigation. Despite clinical cases though, a strong motive for studying phonation could be that there are many languages around the world which employ phonological, segmental voice quality contrasts, chiefly on vowels but on consonants as well, which have not been fully studied yet. Also, another reason to explain the absence of large volume of literature could be that the distinction of phonation types with each other is not always straightforward.

Ladefoged (1971) suggested that there might be a continuum of the different phonation types defined in terms of the aperture between the arytenoid cartilages, ranging from voiceless to breathy to modal and then to creaky and glottal closure. A schematic representation of the continuum can be seen in Figure 2.1:

Figure 2.1 *Continuum of glottal constrictions (after Ladefoged P. 1971), reproduced from Gordon and Ladefoged (2001).*

The different phonation types in Figure 2.1 are contrasted with each other by the various, possible states of the glottis. Beginning with complete abduction of the vocal folds (voiceless) to fairly abducted (breathy-modal), the continuum ends with strictly adducted vocal folds (creaky) and total glottal closure.

However, although one could define a number of voice qualities, the most common contrasting phonation types across and within the languages are three: creaky voice, produced with a constricted glottis; breathy voice, produced with a more open glottis; and modal voice, in between these two (Keating P. A. & Esposito C., 2006*)*. Moreover, since the glottal constriction is defined as continuum there are different degrees of breathiness and creakiness, which are not absolute, and as Ladefoged (1971) suggests, they may vary not only across languages but also across individual speakers.

Moreover, other suggestions about the distinction of voice quality differences have been made. Laver (1980) proposed distinctions between different types of glottal constriction, and between glottal constriction and overall muscular tension. Also, flow through the posterior glottis (“whisper”) provides a noise excitation source that can combine with any other phonation. In addition, the simplified glottal constriction continuum, with its three contrasting categories of voicing and gradient phonetic variation, is similar to the more familiar Voice Onset Time continuum (Blankenship B., 2002). In both cases the articulations involved are more complex than is indicated by the simple names “glottal constriction” or “voice onset time” and, as a result, there can be many acoustic differences among the categories (Keating P. A. & Esposito C., 2006*)*.

Independently of how the different phonation types are defined and contrasted though, the aim of this paper is not to propose a novel phonation distinction scale but to investigate voice quality itself, to measure and detect automatically these acoustic correlates that could be proved as reliable predictors of certain voice qualities in Dinka vowels, breathy voice in particular and to some extent creaky voice as well. More details about the acoustic correlates and measures as well as Dinka language are given in the next sections.

2.1.1 Acoustic correlates of breathy voice

Just like linguists are now aware that fundamental frequency (f_0) and duration are considered strong acoustic correlates of focal accents or that formant frequencies are also robust acoustic correlates of vowel qualities, there must be accordingly some acoustic correlates that are related to each phonation type and, based on them, we should be able to predict different voice qualities without any difficulties. However, due to the lack of extended research on voice quality in general this is not the case.

Despite the fact that research on voice quality is limited, there are, however, some acoustic correlates or tendencies in the acoustic dimension that seem to follow the manifestation of breathy voice and, similarly, the rest of the phonologically contrasted voice qualities, such as creaky voice, in many languages. It could be said that the aforementioned acoustic correlates are more generalizations of acoustic measures which tend to accompany each particular phonation type rather than strong, absolute and well-proved predictors of any voice quality. However, linguists are able to generalize and predict phonation types to a satisfactory degree based on these measurements; therefore they could be considered as reliable acoustic correlates to a certain extent, and as such they will be treated for the rest of this paper. Finally, the reliability of these phonetic properties as acoustic properties of breathy voice will also constitute the hypotheses of this paper's research.

A first strong acoustic correlate that seems to characterize almost all breathy utterances, independently of whether a vowel or a consonant is concerned, is turbulence noise (particularly at high frequencies). Most commonly seen in spectrograms and waveforms of breathy utterances, noisy energy is usually present diminishing the clarity of individual pitch pulses (compared to waveforms and spectrograms of modal utterances). This happens due to the fact that during breathy voice the vocal folds are fairly abducted and as a result the persistent airflow passing through the glottis is relatively higher relative to that of modal voice. Additionally to noisy energy, breathiness is usually also characterized by aperiodic energy in most of the languages that utilize phonological voice quality contrasts (Gordon, M., & Ladefoged, P., 2001). Here is an example:

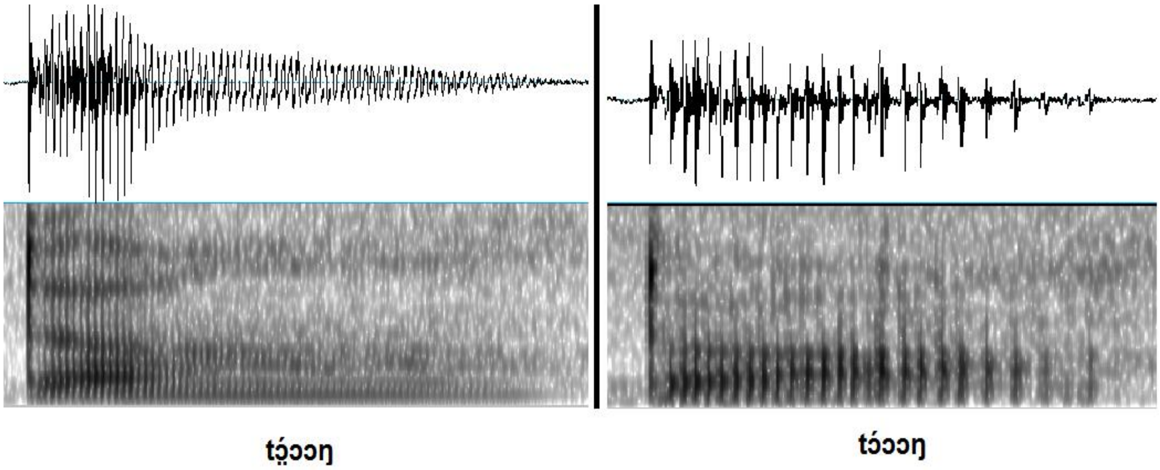

Figure 2.2 *Spectrograms and waveforms excerpts of breathy (left) and creaky (right) vowels in the Dinka words /tɔ̤́ɔɔŋ/ "knock" and /tɔ̰́ɔɔŋ/ "bid goodbye" (female speaker).*

Moreover, breathy as well as creaky phonation is generally associated with differences in energy compared to modal voice and, as a result, with different kinds of measurements related to energy. It has been observed in many languages that breathiness is related with a decrease in overall intensity. Overall intensity, as the name suggests, is the intensity of the whole spectrum. In addition, creakiness is also characterized by a decrease in overall intensity (Gordon, M., & Ladefoged, P., 2001). Similar results in relation with overall intensity and pitch movements were found by Heldner (2002), who found statistical significance in overall intensity for focal accents in Swedish.

Furthermore, Heldner (2002) also found statistically significant correlation between pitch movement, syllable prominence in particular, and spectral emphasis. Spectral emphasis can be described as the relative intensity in the higher frequency bands or, alternatively, the relative contribution of the high-frequency parts of the spectrum to the overall intensity. Gordon and Ladefoged (2001) also suggested that noisy energy can be observed in higher frequencies; therefore it seems that higher frequency bands seem to be an area of the spectrograms worth investigating.

One of the major and possibly the most reliable acoustic correlate of not only breathiness but also of all phonation types is spectral tilt which refers to the degree to which intensity drops off as frequency increases. Spectral tilt is characteristically most steeply positive for creaky vowels and most steeply negative for breathy vowels. That means that the fall off in energy at higher frequencies is least for creaky voice and most for breathy voice (Gordon, M., & Ladefoged, P., 2001). Heldner (2002) also found that along with spectral emphasis, spectral tilt is the most reliable acoustic correlate related to syllable prominence. In agreement with both of the aforementioned studies is also Karlsson (1988; 1992b), who found that the speakers perceived to be breathy in her experiments had higher minimum flows, steeper tilts, and more aspiration noise at mid to high frequencies. Finally, Hanson (1997) found in her experiment a strong correlation between spectral tilt and the articulatory configuration similar to that of breathy voice production.

Another less strong acoustic correlate than spectral tilt but rather consistent is fundamental frequency (f_0). It has been observed that f_0 values are lowered (relative to modal voice) both in breathy and creaky voice, although creakiness does not always stay consistent with its f_0

values. On the other hand, breathiness seems to be more consistent in relation with f_0 values and generally appears to exhibit lowered tone (Gordon, M., & Ladefoged, P., 2001).

Similarly to f_0 values, formant values could also be considered as acoustic correlates for different phonation types, although much less consistent and weaker. In general, it has been observed that creakiness is associated with higher formant frequency values while breathiness with lower formant values (relative to modal voice), especially the first and second formants' values (Kirk P. L., Ladefoged J., & Ladefoged P., 1993). The differences in formants' values are also associated with the raising of the larynx in creaky voice and the lowering of the larynx in breathy voice (Maddieson I. & Ladefoged P., 1985). However, as it has already be mentioned, the findings across languages tend to be inconsistent, thus formant values can be considered as the least reliable acoustic correlate.

Finally, the last acoustic feature that could be considered as acoustic correlate of phonation types is duration, particularly in vowels. It appears that non-modal phonation's vowels tend to be longer compared to modal voice's vowels, especially breathy vowels. This is closely related with physiological constrictions and aerodynamic differences between different voice qualities (Gordon, M., & Ladefoged, P., 2001).

2.1.2 Acoustic measures of breathy voice

Maryn, Roy, De Bodt, Van Cauwenberge and Corthals (2009) conducted a much extended research looking for acoustic markers that have been proposed to be sensitive to and measure overall voice quality using meta-analytic techniques. The acoustic correlates with respect to breathy voice mentioned in the previous section were found to be of great robustness in their findings among others. More particularly, turbulence magnitude (noise), f_0 measurements and intensity related measurements, including spectral tilt, were found statistically significant with mean $r_w < 0.60$, verifying their reliability as acoustic correlates of breathiness. In the diagram depicted in figure 2.3, the organization of the meta-analysis for acoustic measures, including the aforementioned ones, is illustrated:

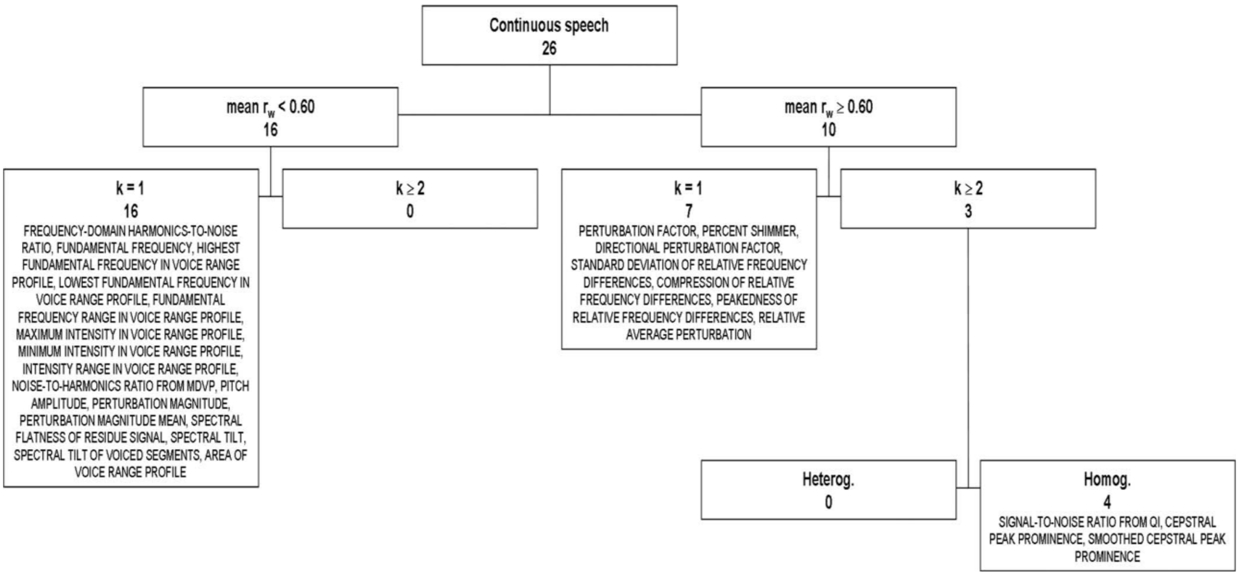

Figure 2.3 *Diagram illustrating the organization of the meta-analysis for acoustic measures. The second line in every box contains the number of acoustic measures*

However, although there may be a number of acoustic correlates related to voice quality, they would only be assumptions if there was not a way to measure them. More specifically, it is necessary for linguists that, besides quality measurements, they are also able to utilize specific measurements in order to run their experiments, quantify their results and generalize them, provided that statistical significance has been found. Therefore, the most significant quantitative measurements are going to be presented in this section with respect to the aforementioned acoustic correlates related to breathy voice. More particularly, the ways which scientists have discovered in order to quantify these acoustic properties using measurements of specific formants or harmonics, periodicity etc. are going to be described and explained.

First of all, among different phonetic properties, some are much easier and straightforward to quantify and others are rather difficult to interpret. Usually, the correlates that need more complicated ways to be measured require the use of automated methods such as scripts or other software, rather than just eyeballing for example waveforms or spectrograms of speech, in order to be considered scientifically reliable. A first example of phonetic correlate that has an uncomplicated way to be measured is duration. Typically, one has only to retrieve the slice of speech that is interested in and measure its duration in seconds, or most commonly in milliseconds (ms) when speech is concerned, usually simply with the aid of software developed for acoustic analysis.

Formant frequencies values are also straightforward to obtain by observing a waveform but in order for someone to get accurate and more reliable measurements they would have to use automated ways such as the use of the appropriate software or a script. Similarly, the same means could be utilized for f_0 values to be estimated.

On the other hand, energy related measurements are more difficult and less straightforward to estimate and the use of specified scripts and software for acoustic analysis seems to be necessary. In order to measure overall intensity, one should take the appropriate energy measures in

Decibels (dB) from the whole spectrum. However, when other kinds of correlates are the aim, first a time window (e.g. Hamming window-25ms) suitable for each study is usually used in time domain or different frequency bands are defined in frequency domain first. For example spectral emphasis is a correlate which, in order for someone to measure it, requires pre-estimated overall intensity values from which the values of the intensity of a signal, that was low-pass filtered at 1.5 times the f_0 mean, is subtracted. In addition, it should be mentioned that there may be several different methods to measure each phonetic property and regarding spectral emphasis in particular there are other more improved measurements than the aforementioned one as well, all calculated in dB (Heldner M., 2002).

The most studied acoustic correlate, hence complicated to measure, for which there are also several different ways to quantify, is spectral tilt. As it was mentioned in the previous section, spectral tilt is considered as the most reliable of the phonetic properties with regards to voice quality and as thus the most commonly used for voice quality research purposes. As Gordon and Ladefoged (2001) state "spectral tilt can be quantified by comparing the amplitude of the fundamental to that of higher frequency harmonics, e.g., the second harmonic, the harmonic closest to the first formant, or the harmonic closest to the second formant". In order for the influence of the formants on harmonics to be avoided, the harmonics are usually first corrected and as thus marked by an asterisk e.g. the strongest corrected harmonic in the third formant peak is symbolized as A3*. Therefore, Sluijter, Agaath and van Heuven (1996), Hanson (1997) as well as Stevens and Hanson (1994) used the difference (in dB) between the first harmonic (H1), equivalent to f_0 and the strongest harmonic in the third formant peak (A3) defined as H1*-

A3* in order to measure spectral tilt. Finally, another related estimate of spectral tilt is the difference between the first and second harmonics (H1-H2) (Jackson M., Ladefoged P., Huffman M., & Antoanzas-Barroso N., 1985; Titze I.R. & Sundberg J., 1992; Campbell W. N., 1995; Campbell W. N. & Beckman M. E., 1997). Here is an example:

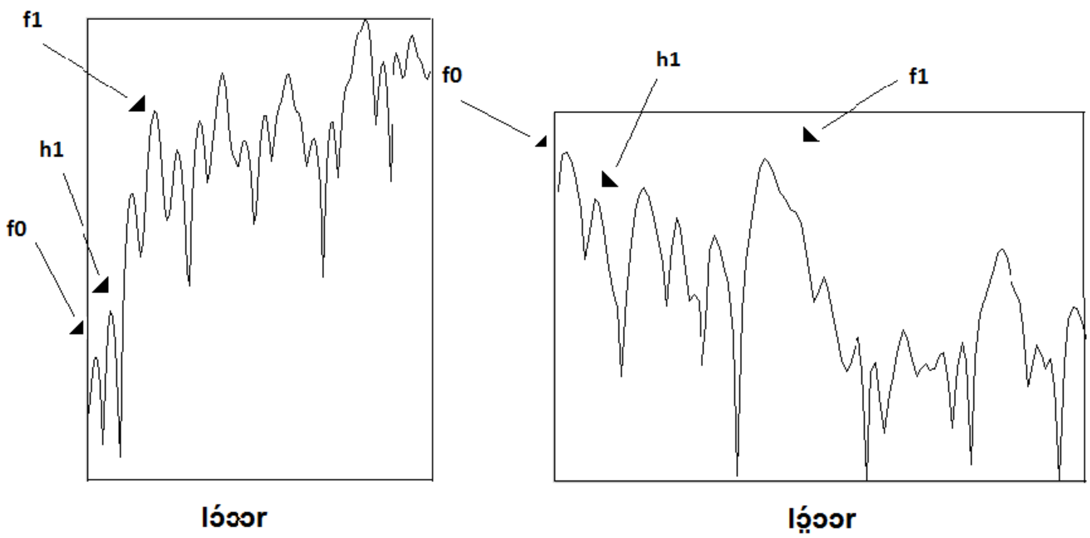

Figure 2.4 *Spectra of creaky (left) and breathy (right) /ɔ/ in the Dinka words /lɔ́ɔɔr/ "roll" and /lɔ̤ɔɔr/ "the place of the drum" (female speaker).*

Apparently, spectral tilt is one of the acoustic correlates that are hard to be measured, since there are a large number of different methods to use. Similarly, there are numerous other phonetic properties related to voice quality with various methods of quantifying them. However, the purpose of this section was not to account for all of them but only for the most reliable ones and show the different ways that one could employ them in practice in order to conduct a research on voice quality.

To summarize, in this section a brief albeit adequate for the purposes of this paper description of the most reliable phonetic properties related to voice quality and breathy voice in particular has been given. Furthermore, a concise presentation of the various and different methods which can be used in order for these properties to be quantified has also been given proving the aforementioned difficulties in relation with voice quality studies generally.

2.2 Dinka language

Dinka is a Western Nilotic language which belongs to the Nilo-Saharan family. Dinka is spoken by around two million people in South Sudan. Dinka people are mainly a nomadic tribe that lives out of livestock and agriculture, although there are several Dinka communities living abroad still speaking their native language. Moreover, Dinka can generally be considered as a language cluster rather than a unified language. More specifically, it is commonly distinguished into four major dialects, according to the areas that they are spoken, which could be divided further into other sub-dialects: Agar, Bor, Padang and Rek. The sub-dialects that are being investigated in this paper are Twic and Malual that belong both to the Rek dialect. At last Dinka is a language with rich suprasegmental and morphological system, as it will be described in the sub-sections below.

2.2.1 Dinka phonology

A basic characteristic of Dinka language is the fact that the stems that are inflected are mostly monosyllabic of the form

(1) C (w) (j) V (V) (V) C,

like their corresponding lexical roots. More particularly, nominal and verbal inflections take place basically by segmental changes in the nucleus and the coda, and by changes in vowel length, tone and voice quality, unlike other languages which utilize affixes. Furthermore, any cases of polysyllabic words can fall under the following three categories: 1) native monomorphemic nouns that consist of two syllables, whose composition is highly constrained: the first syllable is invariably /a/, and the second syllable conforms to the aforementioned template, 2) loan words and 3) native compounds (Remijsen, B. & Manyang C. A., 2009).

The consonantal system of Dinka is relatively simple. As it can be seen in Table 2.1, the inventory consists of twenty consonants among of which there are no fricatives:

	Labial	Dental	Alveolar	Palatal	Velar
Plosive	p b	t̪ d̪	t d	c ɟ	k g
Nasal	m	n̪	n	ɲ	ŋ
Trill			r		
Approximant	w			j	ɰ
Lateral approximant			l		

Table 2.1 *IPA transcription of the consonantal system of Dinka*

Phonetically, all consonants phonemes are realized as implied by the IPA transcription, although there may be some individual exceptions. Some examples are: voiceless plosives may undergo weakening, either to their voiced counterparts or to a homorganic fricative or approximant (e.g. /k/ > [ɰ] and /c/ > [j]) as well as that the plosives may be produced without a release before a phrase boundary or that nasals may be underarticulated in the same context (Andersen, T., 1987; Remijsen, B. & Manyang C. A., 2009).

Moreover, as far as the phonotactics of the consonants is concerned, any consonant can appear in a simple onset, whereas when the onset is complex its composition is severely constrained. The basic limitation is that the initial onset consonant can only be followed by one or two semivowels, as described in the template in (1). Furthermore, /ɰ/ does not appear in complex onsets at all, and onset /n̪ / tends to be followed by /j/. As far as the coda is concerned, there are two restrictions; firstly, voicing in plosives is not distinctive in this slot. On the basis of their phonetic realization in citation form and in phrase-final position, coda plosives are represented as underlyingly voiceless, because unvoiced codas may surface voiced intervocalically and secondly, the semivowel /ɰ/ does not appear in the coda slot, just as it is not found in complex onsets (Andersen, T., 1987; Remijsen, B. & Manyang C. A., 2009).

In contrast with the consonantal system, the vocalic system of Dinka is much more complex predominantly due to the suprasegmental properties which characterize them. There are typically seven different vowel qualities: /i e ɛ a ɔ o u/. All vowel phonemes can combine freely with the three suprasegmental distinctions, voice quality, tone and vowel length, with only two exceptions; firstly, the vowel /u/ is invariably breathy and secondly, the vowel /ɛ/ does not occur in the shortest level of vowel length. As Andersen (1987) states, based on the combinations of the suprasegmental distinctions and voice qualities, the vocalic system consists of eighty-eight distinctive vowels although for simplicity purposes the vowels of Dinka are considered to be the seven aforementioned vowels that can reach up to eighty-eight vowels if suprasegmental distinctions are taken into consideration.

However, it would be wiser if these suprasegmental distinctions are examined independently. The first distinction concerns voice quality, which is also the main objective of investigation of this paper. There are two voice qualities in Dinka: modal and breathy (Remijsen, B. & Manyang C. A., 2009). Andersen (1992-1994) observes a voice quality distinction between creaky and breathy. This difference in terminology is explained by the fact that modal vowels in Dinka usually sound creaky impressionistically or alternatively modal vowels are usually accompanied by a creaky quality. In order not to complicate things and for the reason explained above which generally apply to the dataset under investigation, for the rest of this paper the distinction of voice quality between creaky and breathy is going to be adopted. The acoustic characteristics that make voice qualities distinctive are the same as the ones described in section 2.1.1 and generally apply to Dinka's voice quality distinction. At last, it should been mentioned that Dinka roots can have inherent both creaky and breathy quality. Here are some examples:

Breathy voice	**Creaky voice**
tɛ̤́ɛɛn “there”	t̪ɛ́ɛɛn “fish”
mé̤eek “court: inf”	méeek “court: inf & antip”
bá̤aar “come: imp”	báaar “leave behind: inf”

Figure 2.5 *Minimal pairs of Dinka words between breathy and creaky voice qualities*

However, voice quality alternations can only be found between inherently creaky voice and breathy voice, and no alternations can be found between inherently breathy voice and creaky voice, therefore that makes breathy voice quality the marked type of the voice quality opposition (Andersen T., 1992-1994).

As far as vowel length is concerned, there are three contrasting degrees of vowel length: short, mid and long. They are symbolized by a sequence of one, two and three identical vowel symbols respectively. All vowels can occur with any of the three degrees of vowel length. There is only one exception; that the underlying contrast between /a/ and /ɛ/ seems to be neutralized in the phonetic representation, when the vowel is short. Andersen (1992-1994) argues that the vowel length inherent in a root can be either short or mid and each form is assigned with a specific vowel length depending on the inflectional and the derivational category that belongs to. Therefore, the vowel of a simple root can alternate in length between two sets of vowel length degrees, either between short (CVC) and mid (CVVC) or between mid (CVVC) and long (CVVVC). Moreover, he states that there are also roots that, again depending on their morphological category, may or may not have an inherent, invariant vowel length type. Finally, it should be mentioned that, as it was found by Remijsen and Gilley (2008), the average durations of vowels at least in Luanyjang dialect, sub-dialect of Rek dialect, are 70, 100, and 150 milliseconds for short, mid and long vowel length degrees respectively.

The last suprasegmental distinction is tone. Dinka is a tonal language and exhibits four distinctive tonal patterns; Low, High, Rise and Fall. Each morpheme carries a tone pattern and each pattern associates with the rightmost syllable, which is usually the only syllable (Remijsen, B. & Manyang C. A., 2009). However, unlike voice quality, most roots are not characterized by an inherent, invariable tone pattern but tone assignment is depended basically on the inflectional and derivational categories that are going to be described in the next sub-section, with only exception being the inflectional categories with non-topical subject, which invariantly have a High stem tone. However, in general the tone of a root with a short vowel is either Fall or Low while the tone of a root with a mid vowel is either Fall or High (Andersen T., 1992-1994). Here are some examples:

High tone	Low tone	Fall tone
líiir "cut into strips: inf"	lìiir "cut into strips: antip & 3s	ǎ-lìiir "Declarative-cut into strips: 3s
kí̤iir "pour: inf & antip	kì̤iir "thorny tree"	ǎ-kìiir "Declarative-pour: 3s"
bṳ́uut "soak: inf"	bṳ̀uut "soak: antip & 3s	

Figure 2.6 *Examples of Dinka words that have High, Low and Fall tones.*

Also, often, the sequence of underlyingly specified tone patterns is distorted by contextual effects and by tone sandhi processes. These sandhi processes involve tone absorption and simplification, spreading, rise creation (Andersen T., 1987) and dissimilatory lowering (Remijsen, B. & Manyang C. A., 2009). Finally, tone is independent of voice quality and of vowel length and quality with seemingly the only exception being the contrast between High and Fall that is neutralized on short vowels.

Summarizing, in this sub-section Dinka phonology was described. A brief examination of the relatively simple consonantal system as well as of the rather complex vocal system was provided. However, what seems to be even more perplexing is the rich suprasegmental system of Dinka language. More particularly, the three suprasegmental distinctions were described, namely voice quality, tone system and vowel length. Finally, it has become clearer that Dinka's phonology is very complicated yet intriguing, especially because of the fairly free combination of Dinka vowels with the suprasegmental features.

2.2.2 Dinka morphology

As it has previously been mentioned, Dinka is to its largest extent a monosyllabic language. However, it exhibits an elaborate morphology, just like its rich phonological system. Its morphology is manifested solely by alternations among values of a number of morphophonological parameters of the root including among others the aforementioned voice quality, tone and vowel length. More specifically, as far as the verb roots are concerned, these alternations are exponents of derivation, of subject inflection and of inflection for topic selection (Andersen T., 1992-1994). However, it should be stated that for the purposes of this paper only the most important and related morphological characteristics are going to be described briefly, so as the reader to receive a general idea of Dinka’s morphological structure and its close connection to its phonological system.

First of all, in order for the morphological structure to be described, first the clause structure of Dinka utterances has to be given. A basic distinction in Dinka can be made between declarative and non-declarative clauses. Since there are no non-declarative clauses included in the dataset that this paper is concerned with, only the clause structure of declarative clauses will be given:

(2) Topic Decl (Neg) Verb_{fin} Subject (Object_{dir}) (Verb_{nf}) (Object_{indir}) (Adv)

This clause scheme shows the relative order in which clause constituents occur if they are present and whose slots are finite. In a declarative clause like this, the finite verb is obligatory while any clause has a topic, which occurs clause-initially. The declarative particle is also obligatory and is of the form /à̰-/ after a singular topic and /á̰a-/ or /à̰a-/ after a plural topic. Furthermore, the absence or presence of the declarative particle is the main distinction of declarative and non-declarative clauses (Andersen T., 1992-1994). Moreover, the remaining clause constituents are not obligatory but optional. Additionally, the clauses of the dataset have not such a complicated clause structure. Therefore, for the reasons mentioned above and in order not to complicate things, the rest of the clause constituents are not going to be discussed further.

Furthermore, there are two major morphological categories that are related to the purposes of this paper as well as with verbs included in the utterances of the dataset. To clarify things, by morphological categories are not meant paradigmatic categories like number or person but categories of verb forms with a particular derivational or inflectional meaning, like in Andersen (1992-1994). As thus, the morphological categories that will be described here are the derivational and the inflectional categories.

On the one hand, Dinka has a large number of derivational categories and all of these categories are expressed solely by root-internal alternations, in contrast for example with other languages which employ affixes, and are predominantly productive. The derivational categories that are going to be discussed here are six:

1) Simple stems which are non-derived. They express a root meaning without any modification and are strictly transitive which means that they require a direct object.
2) Centrifugal stems. They indicate that the action is directed from the deictic center which is typically the speaker.

3) Centripetal stems. They indicate that the action is directed towards the deictic center.
4) Benefactive stems. They take a beneficiary object in addition to the patient object of a simple stem. Also either of these semantic roles can be mapped syntactically by the direct object whereas the other becomes an indirect object.
5) Antipassive stems. They demote the object of the corresponding simple stem to an optional adverbial, which is a prepositional phrase with the preposition /è̤/ - /nè̤/.
6) Benefactive-antipassive stems. They combine the syntactic effects of the benefactive and antipassive stems, that is a beneficiary direct object is introduced and the patient object is eliminated (Andersen T., 1992-1994).

Moreover, of these six derivational categories, centripetal, centrifugal and benefactive-antipassive are monotransitive, which means that they require a single direct object, benefactive is ditransitive, which means that it requires two objects, one direct and one indirect, whereas antipassive is intransitive, which takes no direct objects.

On the other hand, the inflectional categories of Dinka are numbered, eleven in particular, a non-finite and ten finite categories. Any verb form belongs to any of these inflectional categories, which are also independent of the derivational categories. Unlike derivational categories which are expressed solely by root-internal alternations, there are inflectional categories that are also expressed only by root-internal alternations but also some that are expressed with suffixation, which, though, can often be accompanied by non-affixal modification of the root as well. Moreover, a verb that belongs to a finite inflectional category is inflected both for subject and for topic selection. More specifically, that is because finite categories express information about subject and topic, namely they indicate whether a clause has a subject or not, or it expresses a pronominal subject. In each case the finite verb also gives some indication of the grammatical relation of the topic (Andersen T., 1992-1994).

Furthermore, finite verbs indicate whether a clause has a topical or a non-topical subject, when the subject is a noun phrase. Therefore, different forms are used for verbs when a clause has a subject topic and when a clause has an object topic or a circumstantial topic. That leads to the distinction that the marked member of this binary opposition is the non-topical subject form whereas the unmarked one is the topical subject. Also, finite verbs can indicate that a clause is passive, that is that it has no grammatical subject, and as a result whether the topic of the clause is a direct object or a circumstantial, although they can co-occur with an agent, which has been demoted to an adverbial. In contrast, finite verbs can also express a pronominal subject, although pronominal subjects are not always expressed by verbs. The expression of a pronominal depends on the following cases: grammatical relation, topicality, position and grammatical relation of the topic. Hence, in declarative clauses a pronominal subject is expressed in the verb if the topic is an object. However, in the case that the verb is intransitive, which is in antipassive derivational category, it cannot be inflected for the subject. With regards to number and person inflection, a plural subject is always expressed by a suffix, a second person singular subject is expressed by a suffix unless the verb stem is either simple or centripetal and a first or third singular is never expressed by a suffix. Also, when inflection does not take place by suffixation, the subject is expressed by the form of the verb stem, although suffixes can also affect the form of the stem, as it has been already mentioned. Finally, as far as non-finite verb forms are concerned, they are utilized in clauses where the finite verb is an auxiliary. In this case, the derivational information is carried by the main verb while the inflectional information is carried by the auxiliary verb (Andersen T., 1992-1994).

It has become clear that the morphological system of Dinka is quite complex. It was shown that a verb form belongs to one of the six derivational categories as well as to one of the eleven inflectional categories. More specifically, a verb is either finite or non-finite and a finite verb is inflected for the grammatical relation of the topic and for the presence or absence of a subject or the person and number of a pronominal subject (Andersen T., 1992-1994). Furthermore, it was explained that derived verb forms are solely expressed by root-internal alternations and that inflected verb forms can be expressed by either only root-internal alternations but by suffixation as well, which, though , could also affect the form of the stem. These root-internal alternations refer to the phonological properties of a root that is the vowel length, the tone and the voice quality of a verb stem. Therefore, there are some phonological properties that are predictable by the morphological status of the verb stem and vice versa. That leads to the fact that, depending on the morphological category that a verb form belongs to, one is possibly able to predict the specific tone, vowel length or voice quality that this verb form carries, although usually other factors affect the phonological status of a verb form which must be taken into account in order for the phonological properties of a stem to be predicted.

More particularly, as far as the derivational categories are concerned, things are more straightforward as the examples that follow show. First, the voice quality in simple and in centrifugal stems is identical with the voice quality inherent in the root. In contrast, in centripetal, benefactive and benefactive-antipassive stems the voice quality is invariably breathy whether the voice quality of the root is creaky or breathy which means as a result that if the root is creaky it shows voice quality alternation but if it is breathy it does not show any alternations. Moreover, regarding vowel length, as it has already been mentioned simple stems can be either short or mid whereas centrifugal and centripetal stems are one degree longer than the corresponding root vowel and benefactive stems are invariably mid. Similar constancy but in more intricate ways can be observed to inflectional categories as well. Verb forms that have a non-topical subject have invariantly a High stem tone. Furthermore, in simple stems the shorter degree occurs always when the inflectional category is for example second singular or first, second or third plural person and the longer degree occurs when the inflectional category is for example first or third singular or when the verb form is non-finite or has non-topical subject. However, in the end there are many verb forms that are neither predictable nor constant and are conditional. That means that depending on the root stem and the inflectional and derivational category that a verb form belongs to, it is attributed with the corresponding phonological properties. Tone alternations for example are in a great extent conditional to root class as well as to the derivational and inflectional status of a verb. Also, antipassive verb forms are to a certain extent characterized by breathy voice but the surface voice quality is dependent to vowel length and tone of the verb. Therefore, as it has been shown, although in their greatest extent the root-internal phonological alternations are conditional and dependent to some particular inflectional and derivational categories, there are some instances, though, where the phonological status of a verb form is predictable by the morphological categories that it belongs to (Andersen T., 1992-1994).

To summarize, the quite rich but rather complicated morphological system of Dinka was described as briefly and adequately as possible. More specifically, firstly the general morphological and syntactical structure of Dinka clauses was given. Secondly, the derivational categories as well as the inflectional categories were introduced and described. Particularly, the way these categories function in a clause was given but the ways that they are expressed by the verb forms were examined as well. Finally, it has been shown that there is a quite strong correlation between Dinka's morphological and phonological systems. That means that the phonological properties of some stems may be totally predictable by the derivational and inflectional categories that a verb belongs to, although in general this is not the case.

Chapter 3

The methodology

In the previous chapter, the theoretical background that someone would require in order to follow the examination of voice quality in Dinka vowels has been provided in short but thoroughly. In this chapter, the more technical details of this paper's work are going to be discussed. More particularly, first some information about the speakers and the dialectal region, that they belong to, will be provided. Then, the dataset is going to be described, the exact nature of the utterances that it consists of and the way the latter will be organized in particular. Finally, the way that the given material is going to be processed and analyzed will be described. More specifically, the exact measurements, which will quantify and represent the data, as well as the automated way that the target values will be extracted with the aid of the appropriate scripts will be described in detail.

3.1 Dialects and speakers

The collection of the data has been obtained by two native Dinka speakers, one male and one female. The female speaker speaks the Twic dialectal variant whereas the male speaker speaks the Malual dialectal variant. Both dialects, though, are sub-dialects and belong to the greater dialect of Rek. According to Roettger and Roettger (1989), the linguistic similarity of both dialects under study is exceptionally high and as a result it will be considered that the whole data belongs to one and only dialect (Rek) and any dialectal differences that may emerge will be ignored.

3.2 Material

First of all, the dataset covers all seven vowel qualities of Dinka that were mentioned above, that is /i e ɛ a ɔ o u/. In order to avoid biases while recording, the vowel qualities were divided into three different blocks with each block having different vowel order: the first block had the order /i ɔ e a o u ɛ/, the second block had the order /a e u o ɛ i ɔ/ and the third block had the order /ɔ ɛ o i e u a/. Furthermore, all target vowels had the long vowel length degree for all examples. That way, it was made possible to avoid any root-internal alternations related complications that may possibly have had arisen e.g. the fact that the vowel /ɛ/ does not occur in the shortest level of vowel length. Therefore, the vowel quality and vowel length factors remained constant within the whole dataset for both speakers.

As a result, what varied in the dataset were the other two phonological properties that a root carries, namely tone and voice quality, which are the main aims of this work. Minimal pairs were created for both of these suprasegmental features. Thus, for each individual vowel quality in each block there was one minimal pair with respect to tone (with the distinction being between High and Low tone) and one minimal pair with respect to voice quality (with the distinction being between creaky and breathy voice). Also, for each vowel quality in each block there was one individual instance of Fall tone which had invariably creaky voice. Here are some examples:

Creaky voice/ High tone	míiit “pull: inf”
Breathy voice/ Low tone	mí̤iit “pull: inf & antip”
Creaky voice/ Low tone	mìiit “pull: antip & 3s”
Breathy voice/ Low tone	mì̤iit “pull: antip & 3s & pet”
Creaky voice/ Fall tone	ǎ-mìiit “Declarative-pull: 3s”

Figure 3.1 *Example of the organization of the data according to voice quality and tone.*

Therefore, in total there were five different examples of the same vowel length for each vowel quality in each block, two minimal pairs of tone and voice quality and one individual example of Fall tone in particular. There was only one exception regarding the high back vowel /u/ which, as it was mentioned before, occurs only in breathy voice, and as thus there was only one minimal pair between High and Low tone for it, with both examples being in breathy voice of course. In Table 3.1, the pattern of the minimal pairs with regards to voice quality and tone which was adopted as well as the Fall tone example can be seen:

Templates	Explanation	
CV́VVC	Creaky voice with High tone	This pattern corresponds to one particular voice quality only (exception: /u/)
CV̤́VVC	Breathy voice with High tone	
CV̀VVC	Creaky voice with Low tone	
CV̤̀VVC	Breathy voice with Low tone	
ă-CV̀VVC	Creaky voice with Fall tone	

Table 3.1 *The pattern of the minimal pairs and the Fall tone example which were adopted for each vowel quality with respect to voice quality and tone*

The aforementioned design of the dataset led to a satisfactory volume of data. More specifically, the dataset comprise one hundred ninety-two distinct examples categorized by tone and voice quality, which, since it was recorded by two speakers, was doubled to three hundred eighty-four distinct examples. Within these examples there were thirty-nine examples of High tone, thirty-nine examples of Low tone, eighteen examples of Fall tone, forty-two examples of breathy voice quality and fifty-four examples of creaky voice quality (the latter ones were more than the breathy voice examples because the Fall tone examples were all in creaky voice). Finally, the volume of the dataset is even bigger if the repetitions of the examples, which were also calculated and analyzed, are taken into consideration.

At last, in order for the minimal pairs to be created and at least one example for each instance of voice quality, tone and vowel quality to be found, a great majority of verb forms were utilized as vessels for the target vowels. However, in few instances where the corresponding contrasting form of a minimal pair could not be expressed by a verb, other lexical categories were also used such as nouns or adverbials. Here are some examples:

Target word	**Clause that includes the target word**
kíiir “pour: inf”	Dèeŋ ǎ-cí̤ pí̤iw kíiir «Deng has poured the water. »
kí̤iir “pour: inf & antip”	Dèeŋ ǎ-cí̤ kí̤iir «Deng has been pouring. »
kìiir “Nile”	Dèeŋ ǎ-tì̤ŋ kìiir «Deng is looking at the Nile. »
kì̤iir “thorny tree”	Dèeŋ ǎ-tì̤ŋ kì̤iir «Deng is looking at the thorny tree. »
ǎa-kìiir “Declarative-pour: 3s”	pí̤iw ǎa-kìiir «The water, he is pouring it. »

Figure 3.2 *Examples of the minimal or near minimal pairs and of the clauses that the dataset consists of.*

Moreover, as it has already been mentioned, all the clauses in the dataset are declarative with only one instance of an imperative clause. That means that there are neither interrogative or exclamatory clauses nor negations in the dataset. In addition, the sentence length is arbitrary as is the word order. The only exception in sentence design is that the word that carries the target vowel is always at the end of a clause, so that the contextual effects to be minimized.

Finally, the morphological status of the target words, that is the derivational and inflectional categories that they belong to, is also arbitrary. More particularly, in order for the minimal pairs to be created, the target words that were selected had any inflectional or derivational category was expressed by the desired root-internal alternations at the time and as thus there is no pattern. However, that causes no implications for the conduct of this paper’s investigation. Collective tables of all the examples of the dataset as well as how the morphological categories were chosen and applied for each example can be found in the Appendix A, categorized by tone and voice quality.

3.3 Procedure

The way that the data is processed is twofold. As it will be described in the paragraphs below, firstly it was necessary that the data was quantified by some specific measurements in the scope of the acoustic correlates that are investigated for the purposes of this paper. Secondly, after the appropriate measurements have been defined, it is useful that the automated ways of how these measurements took place to be described so that the reader to have a better understanding of the computational methods that exist for studies like these.

3.3.1 Quantification of the data

In the previous chapter it was specified that in investigations of acoustic properties like the ones on this paper, first these acoustic properties need to be well-defined quantitatively. There has also been given a brief discussion about some particular measurements and the ways that these can be quantified. In this sub-section, more details will be given about which phonetic correlates are going to be examined as well as the specific measures that these correlates are represented by. Finally, it should also be reminded that the main target of this dissertation is the voice quality in Dinka vowels and secondarily the tone in relation with voice quality.

First of all, the first acoustic correlate that is going to be examined is the formant frequencies. More particularly, the values of the first and the second formants of the target vowels are going to be extracted and then analyzed. As previous studies on the correlation between formant frequencies and voice quality have shown, the first and the second formant of an utterance produced in breathy voice quality have typically lowered values relative to the corresponding values of modal voice production (Gordon, M., & Ladefoged, P., 2001). Formant frequencies is an acoustic correlate that is quite straightforward and has no complicated ways of been measured. More specifically, the measure of formant frequencies is quantified by the values of the formant frequencies themselves. Therefore, in this paper's investigations the same type of measurement is going to be adopted and analyzed as well.

Furthermore, the second acoustic property of Dinka vowels that is going to be examined is the duration of Dinka vowels. More particularly, it has been shown that in breathy voice productions the duration of the vowels tends to be longer relative to modal voice productions (Gordon, M., & Ladefoged, P., 2001). As a result, the main comparison will be conducted between breathy voice and creaky voice, which as it has already been explained, is a conventional term for modal voice productions with some creaky quality. Similarly to formant frequencies, duration as an acoustic correlate is also easy to quantify by simply taking the values of duration of a particular vowel and this is how this kind of measurement will take place in this paper's investigation.

Things are getting more complicated when the next acoustic correlate that will be investigated is concerned, spectral tilt. In the previous chapter, the quantification of spectral tilt was described generally as the comparison of the amplitude of the fundamental frequency to that of higher frequency harmonics (Gordon, M., & Ladefoged, P., 2001). These types of measurement are going to be followed here as well. More specifically, four different measurements of spectral tilt are going to be employed:

i) the comparison of the amplitude of f_0 (H1) to that of the second harmonic (H1-H2)

ii) the comparison of the amplitude of f_0 to that of the most prominent harmonic in the F1 region (H1-A1)

iii) the comparison of the amplitude of f_0 to that of the most prominent harmonic in the F2 region (H1-A2)

iv) and the comparison of the amplitude of f_0 to that of the most prominent harmonic in the F3 region (H1-A3)

(Campbell W. N., 1995; Campbell W. N. & Beckman M. E., 1997; Hanson H. M., 1995; Jackson M. et al., 1985; Sluijter E. J. et al., 1995; Stevens K. & Hanson H. M., 1994; Titze I. R. & Sundberg J., 1992)

As explained in the previous chapter, spectral tilt is one of the most prominent acoustic correlates of phonation types. The difference between the amplitude of H1 and any of the rest of the harmonics under study of a breathy vowel is expected to be greater than that of a modal/creaky vowel More particularly, for breathy voice, spectral tilt values are expected to be found higher than those of creaky phonation, which in contrast are expected to be found lower (Wayland, R. & Jongman A., 2003).

Finally, the last acoustic property that is going to be examined is pitch. As it has already been explained, Dinka is a tonal language, which means that, unlike other languages which use pitch to express emotional and other paralinguistic information and to convey emphasis, it employs pitch (tones) to distinguish lexical or grammatical meaning—that is, to distinguish or inflect words. For the purposes of this paper, pitch is going to be quantified by the values of f_0 since pitch is the perceptual correlate of fundamental frequency. Furthermore, pitch and its movements (tones) are going to be investigated in relation with voice qualities. More specifically, it will be examined whether there is a correlation between a particular tone and a particular voice quality or not.

3.3.2 Automated methods

The previous sub-section was concerned with the quantification of the data and what kind of measurements are going to be employed for the investigation of breathy voice in Dinka vowels. In this sub-section, the automated ways of how these measurements will be processed will be discussed.

As it was mentioned before, the extraction of the aforementioned values happened with the aid of several scripts. The scripts were written and provided by Dr. Bert Remijsen. All scripts were written in Praat scripting language. Also, all measurements and analyses of the acoustic data took place in Praat scientific software program for the analysis of speech in phonetics. The scripts are an easy way to automate all the processes that take place in Praat manually and furthermore to apply these processes to a larger volume of data simultaneously. Some of the scripts were used as a whole just as they were provided by their writer whereas others were modified appropriately to comply with the aims of this paper's investigation. The scripts that were used in this investigation are provided in the Appendix B section.

A script was used for measuring the durations of the vowels. It was used as it was with some slight modifications so that it fitted to the data. The script was straightforward enough since it only tracked the beginnings and the endings of the already segmented and annotated speech utterances and based on these margins it calculated the duration of the in-between space. As it was mentioned, the annotation of the data took place before the actual measurements. More specifically, another script was used that automatically opened the targeted utterances and created Textgrid objects for these utterances at the same time. After the sound and textgrid objects were created then the segmentation and the annotation of the utterances took place manually, and more particularly, the targeted vowels were isolated and annotated in the same way so that the measurement scripts to be applicable universally.

The rest of the measurements were made by two different scripts. The formant frequencies values were extracted first with a particular script. The algorithm for this script is also quite clear to understand. It is a function of the formant frequency references based on the gender of the speaker and the actual formant values. The script recurs over all utterances and applies the same procedure to all data which is based on the formant references that were selected to track the formants on a waveform and extract their values. The waveform and the spectrum of an utterance was also displayed in all repetitions so that the verification of the correct values to take place. Finally, it should be mentioned that in a similar way to the duration script, the midpoint of each segmented and annotated vowel was selected and as thus all the values that were extracted came from the middle of each vowel. This happened predominantly because the middle of a vowel is more stable relative to its boundaries which are prone to co-articulation effects.

Finally, another separate script was used for the rest of the measurements. This script was able to automate several processes simultaneously. More particularly, it calculated and extracted the values of pitch (f_0), the first three formant frequencies as well as the values of the four different kinds of measurements for spectral tilt (H1-H2, H1-A1, H1-A2, H1-A3). It was also modified appropriately so that it fitted the data. Similarly to the formant frequencies script, it also used as a reference the formant frequencies based on speaker's gender given by the user. Furthermore, in similar way to the duration script and just like in formant frequencies script, all the values that were extracted for all the measurements were taken by the middle point of each vowel for the same reason as before. Therefore, all the measurement values that were used for this investigation were based on the values that each vowel had in that instance in the middle.

First, the three formant frequencies were calculated and extracted in the same way as described before. The repetition of this process was a way to verify the reliability of the previous values. Then, pitch was estimated and extracted by using simple commands but defining first the exact point in time that the values would come from. Finally, the A1, A2 and A3 measurements took place. Having already extracted the values of the first three formants, the algorithm located these formants, set some boundaries around the formant regions in the time domain and tracked down the most prominent harmonic within these regions by also setting a threshold in the frequency domain. The calculation of the actual measurements then was just the subtraction of the fundamental frequency, which had been calculated already beforehand, by the three aforementioned harmonics.

In the end, the values that were extracted for all measurements by any script were written out to an output text file. These values were checked for their correctness and then transferred to SPSS predictive analytics software where all the statistical analyses took place. Thus, an outline of the algorithms of the scripts that were used for this study has been given. Moreover, the findings themselves will evaluate the productiveness of the scripts in relation with the task that they are designed to do. More specifically, a basic criterion would be whether the extracted values coincide with the actual values of the processed measurements or there were false estimations howsoever. Also, the scripts will be checked for their universal applicability to the data meaning whether there were any complications with estimating values uniformly and simultaneously. Finally, the assessment for the efficiency of the scripts will be proved and whether they could be utilized by other researchers for similar studies or even for industrial applications as well.

Chapter 4

The findings

The previous chapter described in details the material that was used for this paper's investigation of voice quality in Dinka vowels as well as the procedure that was followed regarding the automated ways for the extraction of the desired values. In this chapter, the results of the analyses of the data are going to be presented and described.

4.1 Duration

The first acoustic property of Dinka vowels that was examined was the duration of the vowels. More particularly, what was tested was whether it would be safe to say that we could predict the voice quality of a vowel based on its duration. The results of the duration analyses are presented in Table 4.1 below. Statistically significant results are denoted with bold:

DURATION						
	Female speaker		Male speaker		Both speakers	
	Mean (ms)	S.D.	Mean (ms)	S.D.	Mean (ms)	S.D.
Creaky voice	190	0.042	**190**	0.046	**190**	0.044
Breathy voice	200	0.046	**220**	0.049	**210**	0.048

Table 4.1 *Means and Standard Deviations of vowel durations for each voice quality and speaker.*

The first column gives the duration results of the female speaker, the second one the results of the male speaker while the last column gives the results of both speakers and as thus the results of the whole data altogether. As it can be seen, the average duration of creaky vowels is the same across and within speakers, namely 190ms. In contrast, the results for breathy vowels vary with the average of 200ms for the female speaker, 220ms for the male speaker and 210ms for the whole data.

As it was expected, the breathy vowels were found to be longer in duration than the creaky vowels in all instances. However, three one-way between subjects ANOVAs were conducted to compare the effect of duration on voice quality for each speaker group. More specifically, statistical significance at the $p<.05$ level was found only for the male speaker's results [$F(1, 245) = 21.7$, $p = .000$] and for both speakers' results [$F(1, 486) = 23$, $p = .000$].

Despite the fact that the female speaker did not show statistically significant results, the rest of the analyses have showed that there is a significant difference between the duration of creaky vowels and breathy vowels, that these differences in duration could predict the voice quality of a vowel in particular. Therefore, the initial hypothesis that duration is an acoustic correlate of voice quality, breathy voice in particular could be retained.

4.2 Formant frequencies

The next acoustic properties that were examined are the formant frequencies of Dinka vowels, the first and the second formant in particular. Since each vowel quality both exhibits and is defined by different formant values for each gender, the results are categorized by the seven vowel qualities that exist in Dinka language for each formant frequency and for each speaker. Also, since there is a clear distinction of formant frequencies between genders (Coleman, R., 1971), the results are presented for each speaker separately. The results can be seen in the collective Table 4.2. Statistically significant results are denoted with bold.

As it can be seen, only one statistically significant difference was found for both creaky and breathy vowels. For each vowel quality and each speaker, one-way between cases ANOVAs were conducted and for each formant frequency individually. Furthermore, the tones that the vowels carried were taken into consideration as well, so that to test any correlation between tone and formant frequency. Finally, it should be reminded that breathy vowels in the given dataset were not found with Fall tone as well as that the high, back vowel /u/ is invariably found in breathy voice in Dinka language.

The only statistically significant result that was shown was by the male speaker. More specifically, the first formant values of the close-mid, front and unrounded vowel /e/ in creaky vowels was found statistically significant [$F(2, 18) = 9.7$, $p = .001$]. However, some very intriguing observations can be made for the rest of the vowel qualities across the speakers as well, despite the fact that there were not found any other statistically significant differences.

Regarding the first formant, on the one hand there is the tendency of lower values for female speaker's breathy vowels with High tone than the creaky ones at all instances. What is unexpected is that in Low tone breathy vowels, where the values are supposed to be lower than the corresponding creaky ones according to the literature (Gordon, M., & Ladefoged, P., 2001), this is not the case. On the other hand, the male speaker exhibits lower values in breathy vowels for only two vowel qualities (/a/, /i/) whereas for the rest of the breathy vowel qualities the values are higher than the creaky ones.

With respect to the second formant, the female speaker had lower values in breathy vowels in two vowel qualities (/e/, /i/) while the rest of the vowels had higher values than the corresponding creaky ones, independently of the tone. In contrast, the male speaker had more higher values for Low tone breathy vowels than the creaky ones whereas the High tone breathy vowels were found to be lower than the creaky ones in three vowel qualities (/a/, /e/, /ɔ/) and higher in the other three qualities (/ɛ/, /i/, /o/).

Moreover, the female speaker seems to have no pattern on Fall tone creaky vowels with regards to the first formant, since the values seem random. However, the corresponding values of the second formant for the same speaker tend to be lower than the rest two tone categories. Similarly, Fall tone creaky vowels with regards to the first formant seem to be random for the male speaker as well as well as the same tendency can be observed for the corresponding values of the second formant for the same speaker.

Finally, due to the lack of adequate number of statistically significant differences as far as the first and second formant frequencies are concerned, the hypothesis that the these formant frequencies constitute acoustic correlates of breathy voice quality in Dinka vowels cannot be further supported in this study. However, it should be noted that the results themselves present some quite interesting relationships between voice qualities and speakers that could possibly be further examined.

FORMANT FREQUENCIES MEANS (Hz)								
Vowel quality			FEMALE SPEAKER			MALE SPEAKER		
			tones			tones		
			HIGH	LOW	FALL	HIGH	LOW	FALL
/a/	CREAKY	F1	830.2	828.8	851.8	763	741	753.4
	BREATHY		727.7	871.1	-	694.4	717.5	-
	CREAKY	F2	1585.2	1549	1684	1358.5	1284.1	1297.8
	BREATHY		1848	1769	-	1292.1	1218.7	-
/e/	CREAKY	F1	442	508	410.8	**448**	**516**	**412.8**
	BREATHY		421.7	528	-	484	564.2	-
	CREAKY	F2	2563.7	2524.8	2589.8	1888.6	1843.7	1767.1
	BREATHY		2392	2256	-	1791	1864.8	-
/ɛ/	CREAKY	F1	714.3	657.5	703.2	647.7	620	638.8
	BREATHY		661.5	622	-	670.8	651.7	-
	CREAKY	F2	2153	2165.3	2242.2	1639.8	1619.8	1686.2
	BREATHY		2267.5	2188.2	-	1700	1728.0	-
/i/	CREAKY	F1	363.5	354.6	349.2	381.2	362	359.1
	BREATHY		336.3	286.6	-	341.1	335.5	-
	CREAKY	F2	2808.7	2812	2772.1	2093.8	2107.2	2100.8
	BREATHY		2676.9	2145.8	-	2112.3	2086.7	-
/o/	CREAKY	F1	466.5	440.5	458	473.7	500.2	496.1
	BREATHY		425.4	711.0	-	527.3	556.0	-
	CREAKY	F2	909.7	809.0	946.2	930.1	955.3	934.5
	BREATHY		1199.2	1982.0		1098.1	1121.1	-
/ɔ/	CREAKY	F1	667	678.8	715.2	645	571.7	674
	BREATHY		625.1	759.8	-	673.2	697.6	-
	CREAKY	F2	1146.0	1124.8	1161.5	1105.8	1118.5	1119.5
	BREATHY		1342.0	1233.1	-	1076.6	1125.3	-
/u/	BREATHY	F1	350.2	507.5	-	376.8	447.1	-
		F2	1337.7	1436.5	-	852.8	1117.1	-

Table 4.2 *The means of the first and second formant (Hz) categorized by the seven vowel qualities of Dinka. The secondary categorization has been done by speaker's gender.*

4.3 Spectral tilt measurements

The last phonetic property of breathy phonation that is going to be presented and analyzed is spectral tilt. As it has already been mentioned, spectral tilt is an acoustic property that can be investigated in several ways, meaning that there are numerous measurements that can be employed in order for spectral tilt to be quantified. Furthermore, it should be reminded that according to the studies that were mentioned in Chapter 2, spectral tilt is considered to be the most reliable acoustic correlate of voice qualities generally and as a result of breathy voice quality in Dinka, which is the main aim of this paper's investigation.

Among others, the four different types of measurements that were investigated and that represent spectral tilt were the following: H1-H2, H1-A1, H1-A2 and H1-A3. In the collective Table 4.3, the means and standard deviations for each measurement can be seen, first for each speaker individually and, second, for both speakers in general. Also, the self-evident distinction between the two voice qualities is also visible both between and within the two speakers. Statistically significant results are denoted with bold.

The most conspicuous fact that can be seen in Table 4.3 is that all results are denoted as statistically significant. One-way between cases ANOVAs were conducted for each measurement and for each speaker and voice quality. Independently of whether the results refer to differences between or within speakers, all measurements of spectral tilt that took place for the investigation of breathy voice quality in Dinka vowels were found statistically significant.

First of all, the comparison of the amplitude of f_0 to that of the second harmonic (H1-H2) was found statistically significant at the $p<.05$

level. More specifically, the between speakers results were found significant at F(1, 184) = 44.9, p = .000 for breathy voice and at F(1, 300) = 11.1, p = .001 for creaky voice whereas the between voice qualities findings were found significant at F(1, 238) = 70, p = .000 for the female speaker and at F(1, 245) = 73.3, p = .000 for the male speaker.

With regards to the comparison of the amplitude of f_0 to that of the most prominent harmonic in the F1 region (H1-A1), between speakers results were found significant at F(1, 184) = 131.5, p = .000 for breathy vowels and at F(1, 300) = 55.1, p = .000 for creaky vowels. Between voice qualities results were found significant at F(1, 238) = 131.8, p = .000 for the female speaker and at F(1, 245) = 100, p = .000 for the male speaker.

SPECTRAL TILT (dB)									
BETWEEN SPEAKERS						WITHIN SPEAKERS			
		Voice quality							
		Creaky		Breathy		Creaky		Breathy	
Measurement	Speaker	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
H1-H2	Female	**-3.83**	**8.08**	**5.00**	**7.73**	**-4.99**	**6.59**	**1.69**	**7.21**
	Male	**-6.29**	**4.18**	**-1.38**	**4.98**				
H1-A1	Female	**-5.35**	**10.89**	**11.01**	**10.48**	**-9.12**	**9.96**	**3.27**	**11.68**
	Male	**-13.06**	**6.73**	**-4.03**	**7.12**				
H1-A2	Female	**5.72**	**11.07**	**20.59**	**9.32**	**1.36**	**10.80**	**13.43**	**11.49**
	Male	**-3.10**	**8.30**	**6.61**	**8.90**				
H1-A3	Female	**15.51**	**12.14**	**26.75**	**10.32**	**11.42**	**10.67**	**22.02**	**10.88**
	Male	**7.32**	**6.98**	**17.43**	**9.26**				

Table 4.3 *Means and Standard Deviations of the four spectral tilt measurements, categorized by voice quality and speaker.*

Furthermore, regarding the comparison of the amplitude of f_0 to that of the most prominent harmonic in the F2 region (H1-A2), between speakers results were found significant at $F(1, 184) = 109.3$, $p = .000$ for breathy voice and at $F(1, 300) = 61.7$, $p = .000$ for creaky voice. Between voice qualities results were found significant at $F(1, 238) = 115.1$, $p = .000$ for the female speaker whereas at $F(1, 245) = 74.7$, $p = .000$ for the male speaker.

Moreover, the comparison of the amplitude of f_0 to that of the most prominent harmonic in the F3 region (H1-A3) was found significant in the between speakers results at $F(1, 184) = 41.9$, $p = .000$ for breathy voice and at $F(1, 300) = 52$, $p = .000$ for creaky voice, while at $F(1, 238) = 54.3$, $p = .000$ for the female speaker and at $F(1, 245) = 93.4$, $p = .000$ for the male speaker in the between voice qualities results.

As far as the within speakers results are concerned, the H1-H2 results were found significant at $F(1, 486) = 109.6$, $p = .000$, the H1-A1 results at $F(1, 486) = 159.6$, $p = .000$, the H1-A2 results at $F(1, 486) = 136.4$, $p = .000$ and finally the H1-A3 results at $F(1, 486) = 111.2$, $p = .000$.

In the end it has become quite straightforward that spectral tilt must be the most reliable acoustic correlate of voice qualities. The evidence is that the analyses of the spectral tilt measurements were found to be all statistically significant. That means that someone based on the spectral tilt measurements would be able to predict the voice quality of Dinka vowels in this study and as a result verify the initial hypothesis that spectral tilt is the most robust acoustic correlate of voice quality in general.

More specifically, the results themselves provide the pattern of how these predictions can be made. First of all, as it was expected (Kirk P. L.

et al., 1993), creaky voice values are all negative and lower than the breathy voice's ones, at least for the first and second spectral tilt measurements (H1-H2 and H1-A1) for both between and within speakers' results. In contrast, again as it was expected, regarding the same measurements the breathy voice values were all positive and higher than creaky voice's ones for both between and within speakers' results as well. Therefore, based on the values of these measurements the voice quality of each group can be predicted with only exception being that the male speaker produced creakier vowels where there should be more breathy. With respect to the third and fourth measurement (H1-A3 and H1-A4), voice quality could also be predicted relied on the results of both speakers with the exception that creaky vowels tend to be less creaky in higher frequencies (such as close to the F3 and F4 region) for both between and within speakers' results. Consequently, based on the aforementioned analyses, the reliability of spectral tilt as acoustic correlate of creaky and breathy voice quality has been shown.

4.4 Voice quality and tone relationship

In the previous sub-sections the reliability of several acoustic properties of voice qualities were examined and analyzed as well as their reliability as acoustic correlates of voice quality, breathy voice in particular, was evaluated. In this sub-section, the secondary goal of this paper's investigation will be presented and analyzed. More particularly, the relationship between certain voice qualities, namely breathy and creaky voice, with the tones that appear of Dinka's phonological system, that is High, Low and Fall, as well as whether there is a correlation between a particular voice quality with a particular tone is going to be described.

In order for this to happen, first voice quality needed to be defined in terms of this investigation. As it has already been mentioned and proven, voice quality can reliably be represented and quantified by the four different spectral tilt measurements, H1-H2, H1-A1, H1-A2 and H1-A3. The dataset was also divided and categorized by vocal register, which is the combination of tone and vowel phonation into a single phonological parameter. Furthermore, the findings were categorized by speaker.

The Pearson product-moment correlation coefficient was calculated for each individual relationship in order for the strength of the linear association between voice quality and tone to be measured. Before proceeding to the results, it should be mentioned that the assumptions that the particular statistical analysis required were all met and that any outliers were first removed before the actual analyses. The collective Table 4.4 presents the findings of this investigation. Statistically significant results are denoted with bold.

First of all, as far as the female speaker is concerned, two statistically significant results were found indicating a strong correlation between creaky voice quality and Low tone. More specifically, the statistical significance was found in the second (H1-A1) [$r = 0.683$, $n = 28$, $p = 0.000$] and third (H1-A2) [$r = 0.687$, $n = 28$, $p = 0.000$] voice quality measurements. Both correlations were positive and indicate that there is a strong association for this particular vocal register that is creaky vowels that carry Low tone for the female speaker of the given dataset.

Furthermore, with regards to the male speaker, another statistically significant correlation was found. More particularly, strong, positive correlations were found for the vocal register of breathy voice with Low tone for the third (H1-A2) [r = 0.613, n = 36, p = 0.000] and fourth (H1-A2) [r = 0.597, n = 36, p = 0.000] voice quality measurements. These findings indicate a strong correlation between breathy voice quality and Low tone at least as far as the male speaker's voice is concerned.

VOCAL REGISTER CORRELATIONS					
		Female speaker		Male speaker	
		Pearson's *r*	Sig. (2-tailed)	Pearson's *r*	Sig. (2-tailed)
Breathy/High	H1-H2	0.037	0.836	-0.099	0.586
	H1-A1	0.043	0.810	**0.304**	0.089
	H1-A2	-0.156	0.383	0.203	0.263
	H1-A3	-0.023	0.898	0.283	0.115
Breathy/Low	H1-H2	0.225	0.206	0.191	0.303
	H1-A1	0.052	0.770	**0.462**	**0.008**
	H1-A2	0.181	0.311	**0.613**	**0.000**
	H1-A3	**0.304**	0.084	**0.597**	**0.000**
Creaky/Fall	H1-H2	0.053	0.803	**0.376**	0.019
	H1-A1	0.107	0.617	**0.348**	0.031
	H1-A2	0.056	0.793	0.014	0.932
	H1-A3	0.093	0.662	**0.307**	0.060
Creaky/High	H1-H2	**-0.331**	0.113	**0.560**	**0.006**
	H1-A1	-0.184	0.388	**0.307**	0.163
	H1-A2	0.248	0.242	**0.395**	0.068
	H1-A3	0.195	0.360	0.129	0.566
Creaky/Low	H1-H2	0.263	0.174	-0.121	0.589
	H1-A1	**0.683**	**0.000**	0.006	0.977
	H1-A2	**0.687**	**0.000**	**-0.304**	0.191
	H1-A3	-0.064	0.744	0.057	0.809

Table 4.4 *Pearson product-moment correlation coefficient findings regarding the association of voice quality with tone.*

However, although there might not have been any further statistically significant findings in terms of p-value significance, there are also some other correlations that may be worth mentioning. On the one hand, as far as the female speaker is concerned, there was an association of medium strength between breathy voice and Low tone with r=.304. According to the studies that were mentioned in Chapter 2, breathy voice generally correlates strongly with Low tone in tonal languages which have this particular vocal register (Gordon, M., & Ladefoged, P., 2001). Therefore, it is unexpected that the female speaker did not exhibit this kind of association like the male speaker did. Furthermore, there was another medium correlation (r=-0.331) between creaky voice and High tone, which would also be expected.

On the other hand, the male speaker seems to demonstrate much more correlations than the female, at least once in all vocal registers that were examined. There were two medium correlations, one between breathy voice and High tone (r=0.304) and one between creaky voice and Low tone (r=-304). It should be reminded that for the latter, statistical significance was also found in female speaker's voice. Moreover, in addition to the statistically significant results of the same speaker regarding the association between breathy voice and Low tone, another medium correlation [r = 0.462, n = 36, p = 0.008] was found for the same vocal register. Furthermore, a strong correlation was found between three of creaky voice's measurements (H1-H2–r=0.376, H1-A1–r=0.348, H1-A3–r=0.307) and Fall tone as well as between three of creaky voice's measurements (H1-H2 – r=0.560, p=0.006, H1-A1 – r=0.307, H1-A2 – r=0.395) and High tone, as expected.

To summarize, in this chapter the analyses that were performed to serve this paper's examination were presented. More particularly, the analyses of the acoustic properties under study were provided as well as their reliability as acoustic correlates of breathy voice quality was assessed. At last, the relationship of certain vocal registers was investigated, whether there are correlations between certain voice qualities with certain tones in particular or not.

Chapter 5

The discussion

So far, the goals for the examination of voice quality in Dinka language have been achieved, as far as it was possible in terms of this paper's length and time limitations. More specifically, first a thorough and adequate presentation of the existing literature on the related subjects of both voice quality in general and Dinka language in particular has been given so that the reader to gain a better understanding of the investigation that took place in this paper. Hopefully, the reader has obtained the appropriate theoretical background to follow and comprehend the findings with ease. Moreover, an explanation of how the material was collected and organized has been given as well as the automated methods that were employed in order for the target values to be extracted, the Praat scripts specifically, were described. That way, the reader will have gained a greater understating of the nature of the utterances that were utilized and of the procedures that took place for their processing. Finally, the findings themselves were presented and analyzed in details. Thus, the reader had the opportunity to exploit their already acquired knowledge and interpret the results less effortlessly. In this last chapter, the findings of the examination of breathy voice quality in Dinka vowels is going to be discussed and analyzed further so that some conclusions to be able to be formed.

First of all, there has already been a brief description of the acoustic correlates of breathy voice in Chapter 2. These correlates were discovered and proposed as such after numerous investigations in voice qualities took place. However, each individual study is applied to an abundant number as well as various scientific objectives. As a result, this means that the findings of a study might not be directly applicable or even to not coincide at all with the findings of another study. For example, there may be two different studies that investigate the same scientific object such as the voice quality in Khmer language on the one hand and in Dinka language on the other hand. However, although the phonological or morphological systems of both languages may be quite similar to each other, the phonetic manifestations of these languages may be very different and as a result the findings of what was the same goal for both languages, voice quality, would end up being dissimilar or even contradictive in some cases.

Consequently, the findings that have been reported in the previous chapter of this paper do not have to howsoever coincide in an absolute degree with the corresponding findings of the same or similar objectives of other studies in the existing literature. With this notion been established, this inevitably means that the findings of the investigation of breathy voice quality in Dinka vowels can and should be interpreted, first of all, uniquely as an individual study of breathy voice in Dinka vowels, secondarily as a study of voice quality in Dinka language and finally comparisons could be made with findings of related studies in similar scientific fields.

Therefore, by following this hierarchy of abstractions in the analysis of the results, the first findings to be discussed are these of the duration of Dinka vowels with respect to breathy voice. The analyses of the results have shown that an association between the duration and voice quality exists indeed, and more specifically that duration could be proved to be reliable as an acoustic correlate of breathy voice, at least in Dinka language.

Specifically, the results of the male speaker and of both speakers in general have shown that longer durations in Dinka vowels come to association with breathiness and as a result creakiness is further associated with shorter durations. In addition, the female speaker's results, although they did not reach statistical significance, however generally followed the same patterns in durations as in the results of the rest two cases. More specifically, the results of the female speaker had almost the same values for breathy vowels with the rest of the cases and the exact same value for the creaky vowels.

Furthermore, these statistically significant differences between the female speaker and the other two speaker groups could be attributed to differences between the genders, for example a hypothesis could be that female speakers produce shorter vowels in Dinka in general than the male ones, a subject that has not been investigated in this paper. Additionally, another influential factor regarding the duration differences could be the potential dialectic differences although this may be less possible to be a cause according to Roettger and Roettger (1989). Finally, despite the individual differences between genders with regards to duration, it should be noted that the findings conform to the findings of the existing literature which states that breathiness is generally associated with longer vowel durations (Gordon, M., & Ladefoged, P., 2001).

Contrary to the findings of duration and the confirmation of its validity as an acoustic correlate of breathiness both by the existing studies and by the results of this paper's investigation, the next phonetic property of Dinka vowels that was investigated seems to not follow the findings of the literature. To be precise, the first and the second formant frequencies were calculated and evaluated as potential acoustic correlates of breathy vowels in Dinka language. It has been shown that the results did not allow any generalizations to be made with respect to formant frequencies and breathiness in terms of statistical significance.

More particularly, only one statistically significant result was found in male speaker's creaky vowels that carried Low tone. Besides this result there have not been found any other results that would indicate that there is any correlation between formant frequencies and any voice quality or tone in Dinka. However, as it has already been mentioned in the previous chapter's analysis of this subject, there are some interesting observations that can be made in the scope of the specific speakers' voices that were examined in this study, which could be included particularly to Dinka language's investigation. The most conspicuous association of breathiness and formant frequencies that has been pointed out in the literature is that the first and the second formant tend to have generally lower values for breathy utterances relative to that of modal utterances (Gordon, M., & Ladefoged, P., 2001). In contrast with these findings, both Dinka speakers of this study seemed to have a tendency for higher values for the breathy vowels relative to them of the creaky vowels, independently of the tone that each vowel carried or voice quality.

More specifically, as far as the first formant is concerned across all vowels qualities the female speaker exhibited in breathy vowels higher values in Low tone and lower values in High tone, which was unexpected since Low tone is considered to be associated with lower formant values and vice versa for High tone (Gordon, M., & Ladefoged, P., 2001). In contrast the male speaker does not seem to follow a pattern with respect to tone but rather having higher first formant frequency values in general. Moreover, regarding the second formant frequency, things are more straightforward since both speakers have showed a clear tendency of higher values for breathy vowels relative to the corresponding creaky ones.

Therefore, it has been shown that there are some clear differences both between voice quality and speakers. Some of these differences can of course been attributed in the gender difference of the two speakers, since formant frequencies are very closely related and sensitive to speaker's gender. Another explanation could be that breathiness in Dinka or even in the specific dialects of the speakers is manifested with such larynx position or pharyngeal width that would not allow lowering of the first or second formant, as literature suggests (Maddieson I. & Ladefoged P., 1985), but in order for this hypothesis to be confirmed further laryngoscopic studies would be required. Nevertheless, independently of the causes of the first two formants values' raising, the verdict is that the first and the second formant were not found to be reliable acoustic correlates of breathy voice in the scope of this study.

Spectral tilt was the next and last potential acoustic correlate of breathy voice that was tested in this study. It has already been mentioned that spectral tilt can be defined as the degree to which intensity drops off as frequency increases (Gordon, M., & Ladefoged, P., 2001). Furthermore, since it is a relative measure, there are several different ways that this acoustic property can be measured and as a result be quantified. Four different measurements have been employed in this study in order for spectral tilt to be calculated and evaluated as acoustic correlate of breathy vowels in Dinka. The findings coincide with the findings of the existing literature as well and have shown that there is a quite strong association of spectral tilt and voice qualities in general.

More particularly, all findings of both speakers individually but of both speakers altogether as well have been found statistically significant. There were also a few intriguing developments with regards to voice qualities that could shed some light on voice quality in Dinka language. First of all, the results have shown that, as far as creaky voice is concerned, the female speaker tends to be less creaky in higher frequencies, in the third formant region in particular, as the H1-A3 measurement suggests. Moreover, as far as breathy voice is concerned, the male speaker tends to be breathier only after the second formant region while he seems to be creaky or modal at the beginnings. Furthermore, in overall with respect to both speakers, although breathiness steadily stays at the expected levels, creakiness seems to fade away at higher frequencies, after the second formant region in particular, according to the H1-A2 and H1-A3 measurements. Of course, this last observation concurs with the female speaker's trend, thus there might be a tendency for creakiness to fade away at higher frequencies for the two speakers or possibly for Dinka in general.

Also, the slight divergences of this study's findings with regards to spectral tilt from the findings of other aforementioned studies in Chapter 2 could also be attributed either to gender differences similarly to the formant frequencies differences or could just be considered as unique characteristics of the specific speakers or Dinka language generally instead of as deviations from a pattern. Independently of any differences or resemblances though, in the end the assessment of this analysis is that spectral tilt has been proven as a reliable acoustic correlate of voice qualities in Dinka language, probably the most reliable one as literature also states.

The primary goal of this study as it has already been explained was to assess the reliability of several phonetic properties as acoustic correlates of breathy voice quality in Dinka vowels. In addition, the secondary aim has also been explored, that is to examine the relationship between voice qualities and tonal patterns in Dinka vowels and whether there are any correlations between them or not. More particularly, Dinka language employs five contrastive vocal registers which means five different combinations of tone and voice quality into a single phonological property. What was investigated, thus, was whether there was a particular statistically significant correlation between specific voice qualities with specific tones. The findings have indicated several such correlations although only a few of them were pointed as statistically significant.

More specifically, the female speaker revealed a strong correlation between creaky voice quality and Low tone. This was unexpected since, as it is suggested in existing literature, Low tone is generally associated with breathiness whereas High tone is associated with creakiness (Gordon, M., & Ladefoged, P., 2001). More consistent with the aforementioned findings were the results of the male speaker who displayed a strong correlation between breathy voice and Low tone. Apart from these strong correlations, there have been disclosed some other observations of medium strength correlations as well between almost all the rests vocal registers. To be more precise, the male speaker was more revealing than the female speaker, since he exhibited medium correlations between all voice qualities and tones whereas the female speaker was less informatory showing a couple of medium correlations only.

These variations between the two speakers, as far as the correlations between voice qualities and tones are concerned, imply for one more time that they could possibly be attributed to gender differences. However, there may be several factors that played role in why only one speaker had such high number of disclosures such as recording issues or even the production effort of each speaker. Finally, though, although it is not possible any generalizations to be made based only on these two speakers, it has been shown at least a hint that there are some strong correlations between certain voice qualities and certain tones in Dinka language.

In the end, unfortunately, the fact that this investigation of breathy voice quality in Dinka vowels was conducted solely on two Dinka speakers, does not allow any generalizations to be made. More particularly, although some of the findings of this study seem to concur with the findings of the existing literature that has been provided in Chapter 2, however, these findings cannot be extended further than this study only. Despite the small number of speakers, the amount of the material, meaning the number of the utterances that were employed for all the examinations, was fairly adequate so that to be able perhaps to generalize within Dinka language. Finally, independently of whether abstractions could be made out of the findings of this study or not, the most important thing is that this paper's investigation has shed even some weak light on the relationship between breathy voice and Dinka language, and could be even of a little help for anyone interested in this subject.

Chapter 6

The conclusion

This dissertation has reached to an end. The reader of this paper should already have gained the sufficient knowledge to comprehend better the terms that have occupied the most of this paper, such as voice quality, Dinka language, automated methods and acoustic correlates. More particularly, the reader should have developed a better understanding of how voice quality is defined and of the acoustic correlates that accompany the different phonation types, of Dinka phonology and morphology and of how the processing of the data took place.

Furthermore, the analyses of the data, the presentation and report of the results and the discussion of the findings should have clarified some facts about the relationship of breathy voice quality, tones and Dinka language in general. Moreover, the review of the existing literature on the scientific fields of voice quality and Dinka language should have helped the reader to further broaden the outcomes of this paper's findings as well as to integrate the work that has been done in this paper into the existing volume of studies.

In conclusion, this dissertation has hopefully given some answers to questions that have little been investigated. More specifically, voice quality is a phonetic process that, as it has already been mentioned, is still being examined in the scope of linguistics, due to the absorption of the majority of studies by the fields of pedagogy and speech pathology. Therefore, this study has shed some light on the purely linguistic notion of the term, in the fields of phonetics and phonology in particular.

Moreover, Dinka, a language with such complex albeit rich phonological and morphological system, has not been investigated thoroughly due to several reasons, such as that there are many Dinka dialects that have often linguistic differences with each other making the investigation of the language difficult, because of the social nature and structure of Dinka people or even due to the fact that emphasis has commonly be given in Indo-European languages by linguists whereas other language families are often disregarded.

Answers or, better, alternative ways have also been provided on the way that linguistic data can be processed. The scripts worked correctly to a great extend with only a few minor exceptions. More particularly, the extracted values were accurate for the majority of the data. Also, the data was processed through by the scripts entirely with no problems. Therefore, it has been shown that the scripts which have been described in this paper could facilitate the work of Praat users, linguists or anyone who is interested in processing linguistic data automatically and uniformly in the future.

Appendix A

Dataset collective tables

Low tone

L	CREAKY	mìiit 'pull:antip&3s'	Dèeŋ ǎ-tḭŋ t̪ɔ̤̀ɔk kṳ̀ mìiit 'Deng looked at the goat and pulled.'
L	BREATHY	mḭ̀iit 'pull:antip&3s&pet' [alt.: 'rainbow']	Dèeŋ ǎ-tḭŋ t̪ɔ̤̀ɔk kṳ̀ mḭ̀iit 'Deng looked at the goat and pulled in.'
L	CREAKY	tɔ̀ɔɔŋ 'knock:antip&3s'	Dèeŋ ǎ-cḭ́ ɰḛ̂eet ɰò̤t-t̪òk kṳ̀ tɔ̀ɔɔŋ 'Deng reached the door and knocked.'
L	BREATHY	tɔ̤̀ɔɔŋ 'bidgoodbye:antip&3s'	Dèeŋ ǎ-cḭ́ rɔ̤́ɔm kèe Bòol kṳ̀ tɔ̤̀ɔɔŋ 'Deng has met Bol and then he said goodbye.'
L	CREAKY	tèeem 'cut:antip&3s'	Dèeŋ ǎ-cḭ́ tìim jò̤ok kṳ̀ tèeem 'Deng found the wood and cut.'
L	BREATHY	tḛ̀eem 'cut:antip&3s&pet'	Dèeŋ ǎ-cḭ́ ɰḛ̂eet wá̤ar-n̪òm kṳ̀ tḛ̀eem 'Deng reached the river and crossed (this way).'
L	CREAKY	bàaal 'tendon'	Dèeŋ ǎ-tḭŋ bàaal 'Deng is looking at the tendon.'
L	BREATHY	bà̤aar 'tall:sg'	Dèeŋ ǎ-tḭŋ tìim bà̤aar 'Deng is looking at a tall tree.'
L	CREAKY	ròoor 'forest' (alt. /ròoom/ 'squeeze:antip&3s')	Dèeŋ ǎ-tḭŋ ròoor 'Deng is looking at forest.' (tìik ǎcḭ́ adwòok ló̤oom kṳ̀ ròoom 'The woman received the gourd and then she squeezed it')
L	BREATHY	rò̤oor 'men'	Dèeŋ ǎ-tḭŋ rò̤oor 'Deng is looking at the men.'
L	BREATHY	dṳ̀uut 'tie.up:antip&3s' [alt.: 'herd:pl']	tìik ǎ-cḭ́ tìim kwàaɲ kṳ̀ dṳ́uut 'The woman collected the wood and then ties up.'
L	CREAKY	kɛ̀ɛɛr 'set.up:antip&1s' [also: kɛ̀ɛɛt̪ 'k.o.gazelle:p']	ɰɛ̀ɛn ǎ-cḭ́ pìɲ jò̤ok kṳ̀ kɛ̀ɛɛr 'I found the plot and set up.'
L	BREATHY	kɛ̤̀ɛɛp 'song,poem:p'	Dèeŋ ǎ-pìŋ kɛ̤̀ɛɛp
L	CREAKY	làaak 'wash:antip&1sg'	ɰɛ̀ɛn ǎ-cḭ́ mèet̪ cɔ́ɔɔl kṳ̀ làaak 'I called the child and then I washed it.'
L	BREATHY	là̤aam 'receive:antip&1sg'	ɰɛ̀ɛn ǎ-cí aláat̪ jô̤ok kṳ̀ là̤aam 'I found the cloth and then I received it.'
L	CREAKY	kèeer 'set.up:antip&3s'	Dèeŋ ǎ-cḭ́ pìɲ jò̤ok kṳ̀ kèeer 'Deng found the plot and set up.'
L	BREATHY	kḛ̀er '-rainy.season'	Dèeŋ ǎ-cḭ́ twàaɲ wà̤a-kḛ̀eer 'Deng became ill last rainy season.'
L	BREATHY	pṳ̀uur 'cultivate:antip&3s'	Dèeŋ a-cḭ́ làa dóoom kṳ̀ pṳ̀uur 'Deng went to the field and then he cultivated.'
L	CREAKY	lòoop 'approach:antip&3s'	Dèeŋ ǎ-cḭ́ bá̤ɲ tḭ̀iŋ kṳ̀ lòoop 'Deng has seen the chief and gone to him.'
L	BREATHY	lò̤oom 'receive:antip&3s'	Dèeŋ ǎ-cí aláat̪ jô̤ok kṳ̀ lò̤oom 'Deng found the cloth and then received it.'
L	CREAKY	rɛ̀ɛɛt 'rip:antip&1s'	ɰɛ̀ɛn ǎ-cḭ́ aláat̪ ló̤oom kṳ̀ rɛ̀ɛɛt 'I received the cloth and ripped it.'
L	BREATHY	rɛ̤̀ɛɛk 'make.to.chain:inf' (also: lɛ̤̀ɛɛt 'insult:pl')	lṳ̀uuŋ ǎ-cḭ́ rɛ̤̀ɛɛk 'The iron has been made to a

			chain.' This infinitive form may be specific to the Twic dialect.
L	CREAKY	lìiir 'cut.i.s:antip&3s'	Dèeŋ ǎ-cḭ́ bjó̰ok tḭiŋ kṵ̀ lìiir 'Deng looked at the hide and cut (into strips).'
L	BREATHY	lḭ̀ir 'cut.i.s:antip&3s&pet' [alt.: ḭ̀r 'jump:inf']	Dèeŋ ǎ-cḭ́ bjó̰ok tḭiŋ kṵ̀ lḭ̀ir 'Deng looked at the hide and then cut towards himself.' alt.: Dèeŋ ǎ-cḭ́ adwɔ̰̀ɔm lḭ̀r 'Deng jumped over the hole (in the ground).' From {lḭr}
L	CREAKY	gɔ̀ɔɔt 'touch:antip&3s'	Dèeŋ ǎ-cḭ́ tìim tḭiŋ kṵ̀ gɔ̀ɔɔt 'Deng looked at the wood and then he touched '
L	BREATHY	gɔ̰̀ɔr 'tribal.marks'	Dèeŋ ǎ-tḭŋ gɔ̰̀ɔr 'Deng is looking at the tribal marks.'
L	CREAKY	lɔ̀ɔɔr 'roll:antip&3s'	Dèeŋ ǎ-cḭ́ tìim tḭiŋ kṵ̀ lɔ̀ɔɔr 'Deng has seen the wood and then he rolls it.'
L	BREATHY	lɔ̰̀ɔr 'drum'	Dèeŋ ǎ-tḭŋ lɔ̰̀ɔr 'Deng is looking at the drum'
L	CREAKY	tɛ̀ɛɛm 'cut:antip&1s' [also: tɛ̀ɛɛl 'wooden.beam:pl']	ɰɛ̀ɛn ǎ-cḭ́ tìim jò̰ok kṵ̀ tɛ̀ɛɛm 'I found the wood and cut.'
L	BREATHY	tɛ̰̀ɛm 'cut:antip&3s&pet'	ɰɛ̀ɛn ǎ-cḭ́ ɰḛ̂eet wá̰ar-n̪òm kṵ̀ tɛ̰̀ɛm 'I reached the river and crossed (this way).'
L	CREAKY	còool 'compensate:antip&3s'	Dèeŋ ǎ-cḭ́ t̪ɔ̰̀ɔk mwɔ̰̀ɔr kṵ̀ còool 'Deng lost the goat and then he compensated it.'
L	BREATHY	cò̰ol 'call:antip&3s&pet'	Dèeŋ á-cḭ́ mèet̪ tḭiŋ ku cò̰ol
L	CREAKY	kìiir 'Nile'	Dèeŋ ǎ-tèem kìiir 'Deng is crossing the Nile.'
L	BREATHY	kḭ̀ir 'thorny.tree'	Dèeŋ ǎ-tḭŋ kḭ̀ir 'Deng is looking at the thorny tree.'
L	CREAKY	mèeek 'court:antip&3s'	Dèeŋ ǎ-cḭ́ ɲàa tḭiŋ kṵ̀ mèeek 'Deng saw the woman met and then he courted.'
L	BREATHY	mḛ̀en 'pole'	Dèeŋ ǎ-tḭŋ mḛ̀en 'Deng is looking at the pole.'
L	BREATHY	bṵ̀ut 'soak:antip&3s'	tìik a-́cḭ́ ràap njâaj ku bṵ̀ut 'The woman took the sorghum and then she soaked.'
L	CREAKY	gàaat̪ 'mark:antip&1sg'	ɰɛ̀ɛn ǎ-cḭ́ Dèeŋ tḭiŋ kṵ̀ gàaat̪ 'I have looked at Deng and then marked (him).'
L	BREATHY	gà̰at 'writing'	Dèeŋ ǎ-tḭŋ gà̰at 'Deng is looking at writing.'

Total examples: 39

High tone

H	CREAKY	míiit ‘pull:inf’	Dèeŋ ă-cḭ́ t̪ɔ̤k míiit ‘Deng has pulled the goat.’
H	BREATHY	mí̤iit ‘pull:inf&antip’	Dèeŋ ă-cḭ́ mí̤iit ‘Deng has been pulling.’
H	CREAKY	tɔ́ɔɔŋ ‘knock:inf’	Dèeŋ ă-cḭ́ ɰɔ̤̀t-t̪òk tɔ́ɔɔŋ ‘Deng has knocked on the door.’
H	BREATHY	tɔ̤́ɔɔŋ ‘bidgoodbye:inf’	Dèeŋ ă-cḭ́ bàaaj tɔ̤́ɔɔŋ ‘Deng has bid goodbye to the household.’
H	CREAKY	téeem ‘cut:inf’	Dèeŋ ă-cḭ́ tìim téeem ‘Deng has cut the wood.’
H	BREATHY	té̤eem ‘cut:inf&antip’	Dèeŋ ă-cḭ́ té̤eem ‘Deng has crossed.’
H	CREAKY	báaar ‘leave.behind:inf’	Dèeŋ ă-cḭ́ mèet̪ báaar ‘Deng has left a child behind.’
H	BREATHY	bá̤aar ‘come:imp’ [also: bá̤aaɲ ‘leadership, kingdom’]	bá̤aar ‘Come!’
H	CREAKY	róoor ‘forest:loc’ (alt. room ‘squeeze:inf’)	Dèeŋ ă-tɔ̤̀ róoor ‘Deng is in the forest.’
H	BREATHY	ró̤ook ‘pray:inf’ (alt.: ‘prayer’)	kɔ́ɔc àacḭ́ ró̤ook ‘The people have prayed.’
H	BREATHY	dṳ́uut ‘tie.up:inf’	tìik ă-cḭ́ tìim dṳ́uut ‘The woman has tied up the wood.’
H	CREAKY	kɛ́ɛɛl ‘fence:loc’	t̪ɔ̤̀k ă-tɔ̀ kɛ́ɛɛl ‘Deng is inside the fence’
H	BREATHY	kɛ̤́ɛɛc ‘strong.man:pl; strength’	Dèeŋ ă-tḭŋ kɛ̤́ɛɛc ‘Deng is looking at strong men.’
H	CREAKY	láaaŋ ‘burden:inf’	Dèeŋ ă-cḭ́ mèet̪ láaaŋ ‘Deng have burdened the child.’
H	BREATHY	rá̤aal ‘vein’	Dèeŋ ă-tḭŋ rá̤aal ‘Deng is looking at a vein’
H	CREAKY	kéeer ‘set.up:inf’	Dèeŋ ă-cḭ́ bàaaj kéeer ‘Deng has set up a house.’
H	BREATHY	ké̤eer ‘branch:sg’ (alt.: ‘rainy season’)	Dèeŋ ă-tḭŋ ké̤eer ‘Deng is looking at a branch.
H	BREATHY	pṳ́uur ‘cultivate:inf’	dòm ací pṳ́uur ‘The field has been cultiavated’
H	CREAKY	lóoop ‘approach:inf’	Dèeŋ ă-cḭ́ ràaan lóoop ‘Deng has gone to somebody.’
H	BREATHY	ló̤oom ‘receive:inf’	tìik ă-cḭ́ aláat̪h ló̤oom ‘The woman has received the cloth.’
H	CREAKY	rɛ́ɛɛŋ ‘grave:loc’	Dèeŋ ă-tɔ̀ rɛ́ɛɛŋ ‘Deng is in the grave.’
H	BREATHY	à-rɛ̤́ɛɛr ‘stay:zero’	Deeŋ à-rɛ̤́ɛɛr ‘Deng is staying’ (Answer to: Cḭ́ Dèeŋ ⍰à̤al? ‘Has Deng gone away?’)
H	CREAKY	líiir ‘cut.i.s:inf’ [alt.: ‘gland.behind.ear’]	Dèeŋ ă-cḭ́ bjó̤ok líiir ‘Deng has cut (into strips) the hide.’
H	BREATHY	lí̤iir ‘cut.i.s:inf&antip’	Dèeŋ ă-cḭ́ lí̤iir ‘Deng has been cutting (into strips).’
H	CREAKY	gɔ́ɔɔt ‘touch:inf’	Dèeŋ ă-cḭ́ tìim gɔ́ɔɔt ‘Deng has touched

			the wood.'
H	BREATHY	gɔ̤́ɔɔr 'leave.behind:inf'	Deeŋ aci gɔ̤́ɔɔr 'Deng is left behind.'
H	CREAKY	lɔ́ɔɔr 'roll:inf' [alt.: 'go:imper']	Déeŋ ă-cḭ́ tììm lɔ́ɔɔr 'Deng has rolled the wood.'
H	BREATHY	lɔ̤́ɔɔr 'drum:loc'	Dèeŋ ă-tɔ̤̀ lɔ̤́ɔɔr 'Deng is in the dancing place (lit. the place of the drum)'
H	CREAKY	t̪ɛ́ɛɛn 'k.o. fish'	Deeŋ ă-dèep t̪ɛ́ɛɛn 'Deng is fishing for [k.o. fish]'
H	BREATHY	tɛ̤́ɛɛn 'there'	Dèeŋ á-tɔ̀ tɛ̤́ɛɛn 'Deng is over there.'
H	CREAKY	cóool 'compensate:inf'	Dèeŋ ă-cḭ́ t̪ɔ̤̀ɔk cóool 'Deng has compensated the goat.'
H	BREATHY	cọ́oot 'call:antip&past'	Dèeŋ ă-cḭ́ cọ́oot 'Deng was calling.'
H	CREAKY	kíiir 'pour:inf' [alt.: 'Nile:loc'; give.present.sisterinlaw]	Dèeŋ ă-cḭ́ pḭ́iw kíiir 'Deng has poured the water.'
H	BREATHY	kḭ́iir 'pour:inf&antip'	Dèeŋ ă-cḭ́ kḭ́iir 'Deng has been pouring.'
H	CREAKY	méeek 'court:inf'	Dèeŋ ă-cḭ́ ɲàa méeek 'Deng has courted a woman.'
H	BREATHY	mẹ́eek 'court:inf&antip'	Dèeŋ ă-cḭ́ mẹ́eek 'Deng has courted.'
H	BREATHY	bṳ́uut 'soak:inf'	tìik ă-cḭ́ rààp bṳ́uut 'The woman has soaked the dura.'
H	CREAKY	gáaat̪ 'mark:inf'	bą́ɲ ẹ́ bíit̪ ă-cḭ́ Dèeŋ gáaat̪ 'The master of the fishing spear has marked Deng'
H	BREATHY	gą́aal 'be.bent:zero'	tìim ă-gą́aal 'The tree is bending.'

<u>Total examples: 39</u>

Fall tone

F	CREAKY	ǎ-mìiit 'decls-pull:3s'	ṯɔ̰ɔk ǎ-mìiit 'The goat, he is pulling it.'
F	CREAKY	ǎ-tɔ̀ɔɔŋ 'decls-knock:3s'	ɰɔ̰̀t-ṯòk ǎ-tɔ̀ɔɔŋ 'The door, he is knocking on it.'
F	CREAKY	ǎ-tèeem 'decls-cut:3s'	tìim ǎ-tèeem 'The wood, he is cutting it'
F	CREAKY	ǎ-bàaar 'decls-leave.behind:1s'	mèeṯ ǎ-bàaar 'I am leabing a child behind.'
F	CREAKY	ǎ-ròoom 'decls-squeeze:3s' (alt. 1.: ée roool 'infertile'; 2. ǎ-ròook 'pay cows for transgression against smb.')	adwòok ǎ-ròoom 'The gourd, she squeezed it.'
F	CREAKY	ǎ-kɛ̀ɛɛr 'decls-set.up:3s'	bàaaj ǎ-kɛ̀ɛɛr 'The house, I am setting it up'
F	CREAKY	ǎ-làaak 'declsg-wash:nts&1sg'	mèeṯ ǎ-làaak 'The child, I am washing it.'
F	CREAKY	ǎ-kèeer 'decls-set.up:3s'	bàaaj ǎ-kèeer 'The house, he is setting it up.'
F	CREAKY	ǎ-lòoop 'decls-approach:3s'	ràaan ǎ-lòoop 'The person, he has gone to him.'
F	CREAKY	ǎ-rɛ̀ɛɛt 'decls- rip:1s'	aláaṯ ǎ-rɛ̀ɛɛt 'The cloth, I have ripped it.'
F	CREAKY	ǎ-lìiir 'decls- cut.i.s:3s'	bjó̰ok ǎ-lìiir 'The hide, he is cutting it (into strips).'
F	CREAKY	ǎ-gɔ̀ɔɔt 'decls- touch:3s'	tìim ǎ-gɔ̀ɔɔt 'The wood, he is touching it.'
F	CREAKY	ǎ-lɔ̀ɔɔr 'decls-roll:antip&3s'	tìim ǎ-lɔ̀ɔɔr 'The wood, Deng rolls it.'
F	CREAKY	ǎ-tɛ̀ɛɛm 'decls-cut:1s'	tìim ǎ-tɛ̀ɛɛm 'The wood, I am cutting it'
F	CREAKY	ǎ-còool 'decls-set.up:3s'	ṯɔ̰̀ɔk ǎ-còool 'The goat, Deng is compensating it.'
F	CREAKY	ǎ-kìiir 'declp-pour:3s'	pḭ́iw ǎa-kìiir 'The water, he is pouring it.'
F	CREAKY	ǎ-mèeek 'decls-cut:3s'	ɲàa ǎ-mèeek 'The girl, he is courting.'
F	CREAKY	ǎ-gàaaṯ 'declsg-mark:nts&1sg'	Dèeŋ ǎ-gàaaṯ 'Deng, I am marking him.'

Total examples: 18

Breathy voice quality

H	BREATHY	mí̤it 'pull:inf&antip'	Dèeŋ ǎ-cí̤ mí̤it 'Deng has been pulling.'
H	BREATHY	tɔ̤́ɔɔŋ 'bidgoodbye:inf'	Dèeŋ ǎ-cí̤ bàaaj tɔ̤́ɔɔŋ 'Deng has bid goodbye to the household.'
H	BREATHY	té̤eem 'cut:inf&antip'	Dèeŋ ǎ-cí̤ té̤eem 'Deng has crossed.'
H	BREATHY	bá̤aar 'come:imp' [also: bá̤aaɲ 'leadership, kingdom']	bá̤aar 'Come!'
H	BREATHY	ró̤ook 'pray:inf' (alt.: 'prayer')	kɔ́ɔc àací̤ ró̤ook 'The people have prayed.'
H	BREATHY	dṳ́uut 'tie.up:inf'	tìik ǎ-cí̤ tìim dṳ́uut 'The woman has tied up the wood.'
H	BREATHY	ké̤ɛɛc 'strong.man:pl; strength'	Dèeŋ ǎ-tì̤ŋ ké̤ɛɛc 'Deng is looking at strong men.'
H	BREATHY	rá̤aal 'vein'	Dèeŋ ǎ-tì̤ŋ rá̤aal 'Deng is looking at a vein'
H	BREATHY	ké̤eer 'branch:sg' (alt.: 'rainy season')	Dèeŋ ǎ-tì̤ŋ ké̤eer 'Deng is looking at a branch.'
H	BREATHY	pṳ́uur 'cultivate:inf'	dòm ací pṳ́uur 'The field has been cultiavated'
H	BREATHY	ló̤oom 'receive:inf'	tìik ǎ-cí̤ aláatẖ ló̤oom 'The woman has received the cloth.'
H	BREATHY	à-ré̤ɛɛr 'stay:zero'	Deeŋ à-ré̤ɛɛr 'Deng is staying' (Answer to: Cí̤ Dèeŋ ⍰a̤al? 'Has Deng gone away?')
H	BREATHY	lí̤iir 'cut.i.s:inf&antip'	Dèeŋ ǎ-cí̤ lí̤iir 'Deng has been cutting (into strips).'
H	BREATHY	gɔ̤́ɔɔr 'leave.behind:inf'	Deeŋ aci gɔ̤́ɔɔr 'Deng is left behind.'
H	BREATHY	lɔ̤́ɔɔr 'drum:loc'	Dèeŋ ǎ-tɔ̤̀ lɔ̤́ɔɔr 'Deng is in the dancing place (lit. the place of the drum)'
H	BREATHY	té̤ɛɛn 'there'	Dèeŋ á-tɔ̀ té̤ɛɛn 'Deng is over there.'
H	BREATHY	có̤oot 'call:antip&past'	Dèeŋ ǎ-cí̤ có̤oot 'Deng was calling.'
H	BREATHY	kí̤iir 'pour:inf&antip'	Dèeŋ ǎ-cí̤ kí̤iir 'Deng has been pouring.'
H	BREATHY	mé̤eek 'court:inf&antip'	Dèeŋ ǎ-cí̤ mé̤eek 'Deng has courted.'
H	BREATHY	bṳ́uut 'soak:inf'	tìik ǎ-cí̤ ràap bṳ́uut 'The woman has soaked the dura.'
H	BREATHY	gá̤aal 'be.bent:zero'	tìim ǎ-gá̤aal 'The tree is bending.'
L	BREATHY	mì̤iit 'pull:antip&3s&pet' [alt.: 'rainbow']	Dèeŋ ǎ-tì̤ŋ t̠ɔ̤̀k kṳ̀ mì̤iit 'Deng looked at the goat and pulled in.'
L	BREATHY	tɔ̤̀ɔɔŋ 'bidgoodbye:antip&3s'	Dèeŋ ǎ-cí̤ rɔ̤́ɔm kèe Bòol kṳ̀ tɔ̤̀ɔɔŋ 'Deng has met Bol and then he said goodbye.'
L	BREATHY	tè̤eem 'cut:antip&3s&pet'	Dèeŋ ǎ-cí̤ ɰê̤eet wá̤ar-n̠òm kṳ̀ tè̤eem 'Deng reached the river and crossed (this way).'
L	BREATHY	bà̤aar 'tall:sg'	Dèeŋ ǎ-tì̤ŋ tìim bà̤aar 'Deng is looking at a tall tree.'
L	BREATHY	rò̤oor 'men'	Dèeŋ ǎ-tì̤ŋ rò̤oor 'Deng is looking at the men.'
L	BREATHY	dṳ̀uut 'tie.up:antip&3s' [alt.: 'herd:pl']	tìik ǎ-cí̤ tìim kwàaɲ kṳ̀ dṳ́uut 'The woman collected the wood and then ties up.'
L	BREATHY	kɛ̤̀ɛɛp 'song,poem:p'	Dèeŋ ǎ-pìŋ kɛ̤̀ɛɛp
L	BREATHY	là̤aam 'receive:antip&1sg'	ɰɛ̀ɛn ǎ-cí aláat̠ jɔ̤̂ok kṳ̀ là̤aam 'I found the cloth and then I received it.'
L	BREATHY	kè̤eer '-rainy.season'	Dèeŋ ǎ-cí̤ twàaɲ wà̤a-kè̤eer 'Deng became ill last rainy season.'
L	BREATHY	pṳ̀uur 'cultivate:antip&3s'	Dèeŋ a-cí̤ làa dóoom kṳ̀ pṳ̀uur 'Deng went to the field and then he cultivated.'
L	BREATHY	lò̤oom 'receive:antip&3s'	Dèeŋ ǎ-cí aláat̠ jɔ̤̂ok kṳ̀ lò̤oom 'Deng found the cloth and then received it.'
L	BREATHY	rɛ̤̀ɛɛk 'make.to.chain:inf'	lṳ̀uuŋ ǎ-cí̤ rɛ̤̀ɛɛk 'The iron has been made to a

		(also: lɛ̤̀ɛɛt 'insult:pl')	chain.' This infinitive form may be specific to the Twic dialect.
L	BREATHY	lı̤̀ir 'cut.i.s:antip&3s&pet' [alt.: ı̤̀ir 'jump:inf']	Dèeŋ ǎ-cı̤́ bjö̤ók tı̤̀iŋ kṳ̀ lı̤̀ir 'Deng looked at the hide and then cut towards himself.' alt.: Dèeŋ ǎ-cı̤́ adwɔ̤̀ɔm lı̤̀ir 'Deng jumped over the hole (in the ground).' From {lı̤r}
L	BREATHY	gɔ̤̀ɔɔr 'tribal.marks'	Dèeŋ ǎ-tı̤̀ŋ gɔ̤̀ɔɔr 'Deng is looking at the tribal marks.'
L	BREATHY	lɔ̤̀ɔɔr 'drum'	Dèeŋ ǎ-tı̤̀ŋ lɔ̤̀ɔɔr 'Deng is looking at the drum'
L	BREATHY	tɛ̤̀ɛɛm 'cut:antip&3s&pet'	ɰɛ̀ɛn ǎ-cı̤́ ɰɛ̤̂eet wá̤ar-n̪òm kṳ̀ tɛ̤̀ɛɛm 'I reached the river and crossed (this way).'
L	BREATHY	cò̤ool 'call:antip&3s&pet'	Dèeŋ á-cı̤́ mèet̪ tı̤̀iŋ ku cò̤ool
L	BREATHY	kı̤̀iir 'thorny.tree'	Dèeŋ ǎ-tı̤̀ŋ kı̤̀iir 'Deng is looking at the thorny tree.'
L	BREATHY	mè̤een 'pole'	Dèeŋ ǎ-tı̤̀ŋ mè̤een 'Deng is looking at the pole.' also means competition.
L	BREATHY	bṳ̀uut 'soak:antip&3s'	tìik a̋-cı̤́ ràap njâaj ku bṳ̀uut 'The woman took the sorghum and then she soaked.'
L	BREATHY	gà̤aat 'writing'	Dèeŋ ǎ-tı̤̀ŋ gà̤aat 'Deng is looking at writing.'

<u>Total examples: 42</u>

Creaky voice quality

F	CREAKY	ǎ-mìiit 'decls-pull:3s'	t̪ɔ̰̀k ǎ-mìiit 'The goat, he is pulling it.'
F	CREAKY	ǎ-tɔ̀ɔɔŋ 'decls-knock:3s'	ɰɔ̰̀t-t̪òk ǎ-tɔ̀ɔɔŋ 'The door, he is knocking on it.'
F	CREAKY	ǎ-tèeem 'decls-cut:3s'	tìim ǎ-tèeem 'The wood, he is cutting it'
F	CREAKY	ǎ-bàaar 'decls-leave.behind:1s'	mèet̪ ǎ-bàaar 'I am leabing a child behind.'
F	CREAKY	ǎ-ròoom 'decls-squeeze:3s' (alt. 1.: ée roool 'infertile'; 2. ǎ-ròook 'pay cows for transgression against smb.')	adwòok ǎ-ròoom 'The gourd, she squeezed it.'
F	CREAKY	ǎ-kɛ̀ɛɛr 'decls-set.up:3s'	bàaaj ǎ-kɛ̀ɛɛr 'The house, I am setting it up'
F	CREAKY	ǎ-làaak 'declsg-wash:nts&1sg'	mèet̪ ǎ-làaak 'The child, I am washing it.'
F	CREAKY	ǎ-kèeer 'decls-set.up:3s'	bàaaj ǎ-kèeer 'The house, he is setting it up.'
F	CREAKY	ǎ-lòoop 'decls-approach:3s'	ràaan ǎ-lòoop 'The person, he has gone to him.'
F	CREAKY	ǎ-rɛ̀ɛɛt 'decls- rip:1s'	aláat̪ ǎ-rɛ̀ɛɛt 'The cloth, I have ripped it.'
F	CREAKY	ǎ-lìiir 'decls- cut.i.s:3s'	bjó̰ok ǎ-lìiir 'The hide, he is cutting it (into strips).'
F	CREAKY	ǎ-gɔ̀ɔɔt 'decls- touch:3s'	tìim ǎ-gɔ̀ɔɔt 'The wood, he is touching it.'
F	CREAKY	ǎ-lɔ̀ɔɔr 'decls-roll:antip&3s'	tìim ǎ-lɔ̀ɔɔr 'The wood, Deng rolls it.'
F	CREAKY	ǎ-tɛ̀ɛɛm 'decls-cut:1s'	tìim ǎ-tɛ̀ɛɛm 'The wood, I am cutting it'
F	CREAKY	ǎ-còool 'decls-set.up:3s'	t̪ɔ̰̀k ǎ-còool 'The goat, Deng is compensating it.'
F	CREAKY	ǎ-kìiir 'declp-pour:3s'	pḭ́iw ǎa-kìiir 'The water, he is pouring it.'
F	CREAKY	ǎ-mèeek 'decls-cut:3s'	ɲàa ǎ-mèeek 'The girl, he is courting.'
F	CREAKY	ǎ-gàaat̪ 'declsg-mark:nts&1sg'	Dèeŋ ǎ-gàaat̪ 'Deng, I am marking him.'
H	CREAKY	míiit 'pull:inf'	Dèeŋ ǎ-cḭ́ t̪ɔ̰̀k míiit 'Deng has pulled the goat.'
H	CREAKY	tɔ́ɔɔŋ 'knock:inf'	Dèeŋ ǎ-cḭ́ ɰɔ̰̀t-t̪òk tɔ́ɔɔŋ 'Deng has knocked on the door.'
H	CREAKY	téeem 'cut:inf'	Dèeŋ ǎ-cḭ́ tìim téeem 'Deng has cut the wood.'
H	CREAKY	báaar 'leave.behind:inf'	Dèeŋ ǎ-cḭ́ mèet̪ báaar 'Deng has left a child behind.'
H	CREAKY	róoor 'forest:loc' (alt. room 'squeeze:inf')	Dèeŋ ǎ-tɔ̰̀ róoor 'Deng is in the forest.'
H	CREAKY	kɛ́ɛɛl 'fence:loc'	t̪ɔ̰̀k ǎ-tɔ̀ kɛ́ɛɛl 'Deng is inside the fence'
H	CREAKY	láaaŋ 'burden:inf'	Dèeŋ ǎ-cḭ́ mèet̪ láaaŋ 'Deng have burdened the child.'
H	CREAKY	kéeer 'set.up:inf'	Dèeŋ ǎ-cḭ́ bàaaj kéeer 'Deng has set up a house.'
H	CREAKY	lóoop 'approach:inf'	Dèeŋ ǎ-cḭ́ ràaan lóoop 'Deng has gone to somebody.'
H	CREAKY	rɛ́ɛɛŋ 'grave:loc'	Dèeŋ ǎ-tɔ̀ rɛ́ɛɛŋ 'Deng is in the grave.'
H	CREAKY	líiir 'cut.i.s:inf' [alt.: 'gland.behind.ear']	Dèeŋ ǎ-cḭ́ bjó̰ok líiir 'Deng has cut

			(into strips) the hide.’
H	CREAKY	gɔ́ɔɔt ‘touch:inf’	Dèeŋ ǎ-cį́ tìim gɔ́ɔɔt ‘Deng has touched the wood.’
H	CREAKY	lɔ́ɔɔr ‘roll:inf’ [alt.: ‘go:imper’]	Déeŋ ǎ-cį́ tìim lɔ́ɔɔr ‘Deng has rolled the wood.’
H	CREAKY	t̪ɛ́ɛɛn ‘k.o. fish’	Deeŋ ǎ-dèep t̪ɛ́ɛɛn ‘Deng is fishing for [k.o. fish]’
H	CREAKY	cóool ‘compensate:inf’	Dèeŋ ǎ-cį́ t̪ɔ̰̀k cóool ‘Deng has compensated the goat.’
H	CREAKY	kíiir ‘pour:inf’ [alt.: ‘Nile:loc’; give.present.sisterinlaw]	Dèeŋ ǎ-cį́ pį́iw kíiir ‘Deng has poured the water.’
H	CREAKY	méeek ‘court:inf’	Dèeŋ ǎ-cį́ ɲàa méeek ‘Deng has courted a woman.’
H	CREAKY	gáaat̪ ‘mark:inf’	bá̰ɲ ẹ́ bíit̪ ǎ-cį́ Dèeŋ gáaat̪ ‘The master of the fishing spear has marked Deng’
L	CREAKY	mìiit ‘pull:antip&3s’	Dèeŋ ǎ-tı̰̀ŋ t̪ɔ̰̀k kṵ̀ mìiit ‘Deng looked at the goat and pulled.’
L	CREAKY	tɔ̀ɔɔŋ ‘knock:antip&3s’	Dèeŋ ǎ-cį́ ɰệeet ɰọ̀t-t̪òk kṵ̀ tɔ̀ɔɔŋ ‘Deng reached the door and knocked.’
L	CREAKY	tèeem ‘cut:antip&3s’	Dèeŋ ǎ-cį́ tìim jọ̀ok kṵ̀ tèeem ‘Deng found the wood and cut.’
L	CREAKY	bàaal ‘tendon’	Dèeŋ ǎ-tı̰̀ŋ bàaal ‘Deng is looking at the tendon.’
L	CREAKY	ròoor ‘forest’ (alt. /ròoom/ ‘squeeze:antip&3s’)	Dèeŋ ǎ-tı̰̀ŋ ròoor ‘Deng is looking at forest.’ (tìik ǎcį́ adwòok lọ́oom kṵ̀ ròoom ‘The woman received the gourd and then she squeezed it’)
L	CREAKY	kɛ̀ɛɛr ‘set.up:antip&1s’ [also: kɛ̀ɛɛt̪ ‘k.o.gazelle:p’]	ɰɛ̀ɛn ǎ-cį́ pı̀ɲ jọ̀ok kṵ̀ kɛ̀ɛɛr ‘I found the plot and set up.’
L	CREAKY	làaak ‘wash:antip&1sg’	ɰɛ̀ɛn ǎ-cį́ mèet̪ cɔ́ɔɔl kṵ̀ làaak ‘I called the child and then I washed it.’
L	CREAKY	kèeer ‘set.up:antip&3s’	Dèeŋ ǎ-cį́ pı̀ɲ jọ̀ok kṵ̀ kèeer ‘Deng found the plot and set up.’
L	CREAKY	lòoop ‘approach:antip&3s’	Dèeŋ ǎ-cį́ bá̰ɲ tı̰̀iŋ kṵ̀ lòoop ‘Deng has seen the chief and gone to him.’
L	CREAKY	rɛ̀ɛɛt ‘rip:antip&1s’	ɰɛ̀ɛn ǎ-cį́ aláat̪ lọ́oom kṵ̀ rɛ̀ɛɛt ‘I received the cloth and ripped it.’
L	CREAKY	lìiir ‘cut.i.s:antip&3s’	Dèeŋ ǎ-cį́ bjọ́ok tı̰̀iŋ kṵ̀ lìiir ‘Deng looked at the hide and cut (into strips).’
L	CREAKY	gɔ̀ɔɔt ‘touch:antip&3s’	Dèeŋ ǎ-cį́ tìim tı̰̀iŋ kṵ̀ gɔ̀ɔɔt ‘Deng looked at the wood and then he touched ’
L	CREAKY	lɔ̀ɔɔr ‘roll:antip&3s’	Dèeŋ ǎ-cį́ tìim tı̰̀iŋ kṵ̀ lɔ̀ɔɔr ‘Deng has seen the wood and then he rolls it.’
L	CREAKY	tɛ̀ɛɛm ‘cut:antip&1s’ [also: tɛ̀ɛɛl ‘wooden.beam:pl’]	ɰɛ̀ɛn ǎ-cį́ tìim jọ̀ok kṵ̀ tɛ̀ɛɛm ‘I found the wood and cut.’
L	CREAKY	còool ‘compensate:antip&3s’	Dèeŋ ǎ-cį́ t̪ɔ̰̀k mwɔ̰̀ɔr kṵ̀ còool ‘Deng lost the goat and then he compensated it.’
L	CREAKY	kìiir ‘Nile’	Dèeŋ ǎ-tèem kìiir ‘Deng is crossing the Nile.’
L	CREAKY	mèeek ‘court:antip&3s’	Dèeŋ ǎ-cį́ ɲàa tı̰̀iŋ kṵ̀ mèeek ‘Deng saw the woman met and then he

			courted.’
L	CREAKY	gàaat̪ ‘mark:antip&1sg’	ɰɛ̀ɛn ǎ-cḭ́ Dèeŋ t̪ḭiŋ kṳ̀ gàaat̪ ‘I have looked at Deng and then marked (him).’

Total examples: 54

TOTAL DISTINCT EXAMPLES CATEGORISED BY TONE AND VOICE QUALITY: 192

NUMBER OF SPEAKERS: 2

TOTAL FOR BOTH SPEAKERS: 384 (EXCLUDING REPETITIONS)

Appendix B

Praat scripts

Open multiple files and create Textgrid objects simultaneously script

```
# created: 13-09-2005

# by: Bert Remijsen


form Read files into Praat Object window

comment Fields in filenames are separated by underscores.

comment A file is read if the specified value is found in the specified field.

word location ‘insert dir’

comment Search based on file name; underscore is field separator:

word searchterm *e.g.*

endform

Create Strings as file list... listfile 'location$'\'searchterm$'.wav

last = Get number of strings

for fileteller from 1 to 'last'

  select Strings listfile

  stringx$ = Get string... 'fileteller'

  Read from file... 'location$'\'stringx$'

  To TextGrid... seg

endfor

select Strings listfile

Remove
```

Duration script

```
# created: 13-09-2005

# by: Bert Remijsen



# The section between 'form' and 'endform' places a window on the screen

# via which the user can control the parameters of the script.

form Measure durations

  comment Name of the text file with list of filenames (without its extension [.txt]):

  word listfile lst

  comment inputlist and files are located in (directory):

  word inputdir ‘insert dir’

  comment The segments are located in tier number:

  integer tier_number 1

  comment output gets written to (path and filename incl extension):

  word output ‘insert name’

endform

# Read the list of files

Read Strings from raw text file... 'inputdir$'/'listfile$'.txt

end = Get number of strings

# For each file in the list, the script carries out all the commands between

# 'for' and 'endfor'

for filecounter from 1 to 'end'

# assign the filename of the current item to a variable

  select Strings 'listfile$'

  file$ = Get string... 'filecounter'

# read the TextGrid file associated with this filename into Praat

  Read from file... 'inputdir$'/'file$'.TextGrid

# This part of the script extracts the labels, start and end values

# of the segments of interest from the TextGrid object. The values

# are then used to determine the segment durations.

  nlabels = Get number of intervals... 'tier_number'

  for label from 1 to 'nlabels'

  labelx$ = Get label of interval... 'tier_number' 'label'

  if (labelx$ = "n")

    nucleus_begin = Get starting point... 'tier_number' 'label'

    nucleus_end = Get end point... 'tier_number' 'label'

    nucleus_duration = 'nucleus_end' - 'nucleus_begin'

  endif

  endfor

# The durational measurements are appended to a textfile. If the textfile

# does not yet exist, it is created.

  echo 'file$' 'nucleus_duration:2'

  fappendinfo 'output$'

# clean up - remove the TextGrid file

  select all

  minus Strings 'listfile$'

  Remove

# end of the loop; if there are more items in the list of filenames the script

# continues with the next item.
```

endfor	select Strings 'listfile$'
# end of the script; clean up of the list of filenames	Remove

Formant frequencies script

USAGE:

This script calculates F1 and F2 at the midpoint of a

specific segment in a TextGrid file. The procedure is

repeated made for each occurrence of that segment in the

TextGrid. The label needs to be specified by the user.

F1 and F2 are calculated using 'To formant (burg)' and

and the tracker. Both of these algorithms set parameters

as a function of speaker sex. This parameter is controlled

by the user. The Picture window shows the spectrogram and

formant tracks (F1 & F2), and The rounded F1 and F2 values

appear at the top. As an additional check, and for voice quality measurements,

the script displays the spectrum, the Long-term average

spectrum (Ltas) and the LPC spectrum at the bottom. The

LPC spectrum at the bottom uses the 'autocorrelation'

algorithm, which is differen from the 'burg' algorithm

by means of which the values at the top are computed.

When the 'To formant' and 'Track...' procedures do not

produce plausible formant values, the user can (1) run the

script again with new tracking values, (2) on the basis

of the spectrum/Ltas/LPC display at the bottom part of

the Picture window, determine F1 and F2 by hand using

the Spectrum/Ltas/LPC in the Object window.

The script can be modified to produce measurements on voice

quality with a check.

BY: Bert Remijsen

DATE: 13/12/2011

form Calculate F1 & F2 for a specific segment (batch)

comment See header of script for details.

comment Directory of input and output files; text file (no extension) w. list of filenames (no extensions); output file:

word directory 'insert dir'

word searchterm *e.g.*

word outputfile 'insert name'

comment The label of segments to be measured, and the tier in the TextGrid, and the speaker's sex:

word the_label n

integer the_tier 1

optionmenu sex 1

option male

option female

comment Length of window over which spectrogram is calculated:

positive length 0.005

optionmenu play 1

option yes

```
  option no
  comment Settings for Track... algorithm (MALE on the left; FEMALE on the right)
  positive left_F1_reference 500
  positive right_F1_reference 550
  positive left_F2_reference 1485
  positive right_F2_reference 1650
  positive left_F3_reference 2475
  positive right_F3_reference 2750
  positive left_Frequency_cost 1
  positive right_Frequency_cost 1
  positive left_Bandwidth_cost 1
  positive right_Bandwidth_cost 1
  positive left_Transition_cost 1
  positive right_Transition_cost 1
endform


clearinfo
# Recursion over files
Create Strings as file list... listfile 'directory$'\'searchterm$'.TextGrid
end = Get number of strings
for filecounter from 1 to end
select Strings listfile
file$ = Get string... filecounter
Read from file... 'directory$'\'file$'
textgridID = selected("TextGrid")
filebare$ = file$ - ".TextGrid"
Read from file... 'directory$'\'filebare$'.wav
soundID = selected("Sound")
select 'textgridID'
plus 'soundID'
counter = 0
exclude = index(file$, "1SG")
if (exclude == 0)
select 'textgridID'
finishing_time = Get finishing time
nlabels = Get number of intervals... 'the_tier'
for label from 1 to 'nlabels'
  select 'textgridID'
  labelx$ = Get label of interval... 'the_tier' 'label'
  if (labelx$ = the_label$)
    counter = counter + 1
    n_b = Get starting point... 'the_tier' 'label'
    n_e = Get end point... 'the_tier' 'label'
    n_d = 'n_e' - 'n_b'
    n_md = ('n_b' + 'n_e') / 2
    call vowelq 'n_b' 'n_e' 'n_md' 'filebare$'
  endif
  select 'textgridID'
  plus 'soundID'
endfor
# deze endif hoort bij de exclude if
endif
# Recursion over files
select 'textgridID'
plus 'soundID'
Remove
endfor
procedure vowelq n_b n_e n_md filebare$
# set maximum frequency of Formant calculation algorithm on basis of sex
```

```
# sex is 1 for male (left); sex is 2 for remale (right).

 if ('sex' = 1)

   maxf = 5000

  f1ref = left_F1_reference

  f2ref = left_F2_reference

  f3ref = left_F3_reference

  f4ref = 3465

  f5ref = 4455

  freqcost = left_Frequency_cost

  bwcost = left_Bandwidth_cost

  transcost = left_Transition_cost

 endif

 if ('sex' = 2)

   maxf = 5500

  f1ref = right_F1_reference

  f2ref = right_F2_reference

  f3ref = right_F3_reference

  f4ref = 3850

  f5ref = 4950

  freqcost = right_Frequency_cost

  bwcost = right_Bandwidth_cost

  transcost = right_Transition_cost

 endif

 select 'soundID'

 Resample... 16000 50

 sound_16khz = selected("Sound")

 To Formant (burg)... 0.01 5 'maxf' 0.025 50

 Rename... 'filebare$'_beforetracking

 formant_beforetracking = selected("Formant")

 Track... 3 'f1ref' 'f2ref' 'f3ref' 'f4ref' 'f5ref' 'freqcost' 'bwcost' 'transcost'

 Rename... 'filebare$'_aftertracking

 formant_aftertracking = selected("Formant")

 Save as text file... 'directory$'\'filebare$'.Formanttt

# Get the f1,f2,f3 measurements.

 select 'formant_aftertracking'

 f1hzpt = Get value at time... 1 'n_md' Hertz Linear

 f2hzpt = Get value at time... 2 'n_md' Hertz Linear

 f3hzpt = Get value at time... 3 'n_md' Hertz Linear

# display the formant tracks overlaid on spectrogram.

  Erase all

  Font size... 14

  display_from = 'n_b' - 0.15

  if ('display_from' < 0)

    display_from = 0

  endif

  display_until = 'n_e' + 0.15

  if ('display_until' > 'finishing_time')

    display_until = 'finishing_time'

  endif

  select 'soundID'

  To Spectrogram... 'length' 4000 0.002 20 Gaussian

  spectrogram = selected("Spectrogram")

  Viewport... 0 7 0 3.5

  Paint... 'display_from' 'display_until' 0 3250 100 yes 50 6 0 no

  select 'formant_aftertracking'

  Yellow
```

```
  Speckle... 'display_from' 'display_until' 3250 30 no
  Marks left every... 1 500 yes yes yes
  Viewport... 0 7 0 4
  select 'textgridID'
  Black
  Draw... 'display_from' 'display_until' no yes yes
  One mark bottom... 'n_md' yes yes yes
  rf1hzpt = round('f1hzpt')
  rf2hzpt = round('f2hzpt')
  Text top... no Tracker output -- F1: 'rf1hzpt' ***** F2: 'rf2hzpt'
# display the spectrum, with Ltas and LPC
  select 'sound_16khz'
  spectrum_begin = n_md - 0.015
  spectrum_end = n_md + 0.015
  Extract part...  'spectrum_begin' 'spectrum_end' Hanning 1 no
  Rename... 'filebare$'_slice
  sound_16khz_slice = selected("Sound")
  To Spectrum (fft)
  spectrum = selected("Spectrum")
  Viewport... 0 7 4 6.5
  Draw... 0 3250 0 80 yes
  To Ltas (1-to-1)
  ltas = selected("Ltas")
  Viewport... 0 7 4 6.5
  Draw... 0 3250 0 80 no bars
  Marks bottom every... 1 500 yes yes no
  Marks bottom every... 1 250 no no yes
  select 'sound_16khz'
  To LPC (autocorrelation)... 18 0.025 0.005 50
  lpc = selected("LPC")
  To Spectrum (slice)... 'n_md' 20 0 50
  Rename... LPC_'filebare$'
  spectrum_lpc = selected("Spectrum")
  select 'lpc'
  Remove
 select 'spectrum_lpc'
  Line width... 2
  Draw... 0 3250 0 80 no
  Line width... 1
  Text top... no Spectrum [30 ms], Ltas(1-to-1) [30 ms], LPC(autocorrelation), all three overlaid
  if ('play' = 1)
    select 'soundID'
    Extract part... 'display_from' 'display_until' Hanning 1 no
    Play
   Remove
  endif
fileappend 'directory$'\'outputfile$' 'file$' 'f1hzpt:1' 'f2hzpt:1' 'newline$'
echo Settings F1ref:'f1ref' *** F2ref:'f2ref' *** F3ref:'f3ref' *** F4ref:'f4ref' *** F5ref:'f5ref' *** Frequency cost:'freqcost' *** Bandwidth cost:'bwcost' *** Transition cost:'transcost'
  select 'spectrum_lpc'
  pause ok? [occurrence 'counter' of segment 'the_label$']
  select 'spectrum_lpc'
  plus 'spectrum'
  plus 'spectrum'
  plus 'ltas'
  plus 'spectrogram'
  plus 'formant_beforetracking'
```

```
plus 'formant_aftertracking'
plus 'sound_16khz'
plus 'sound_16khz_slice'
Remove
endproc
```

Spectral tilt script (plus formant frequencies and pitch measurements)

USAGE:

This script calculates F1 and F2 at the midpoint of a

specific segment in a TextGrid file. The procedure is

repeated made for each occurrence of that segment in the

TextGrid. The label needs to be specified by the user.

F1 and F2 are calculated using 'To formant (burg)' and

and the tracker. Both of these algorithms set parameters

as a function of speaker sex. This parameter is controlled

by the user. The Picture window shows the spectrogram and

formant tracks (F1 & F2), and The rounded F1 and F2 values

appear at the top.

As a additional check, and for voice quality measurements,

the script displays the spectrum, the Long-term average

spectrum (Ltas) and the LPC spectrum at the bottom. The

LPC spectrum at the bottom uses the 'autocorrelation'

algorithm, which is differen from the 'burg' algorithm

by means of which the values at the top are computed.

When the 'To formant' and 'Track...' procedures do not

produce plausible values, the user can (1) run the

script again with new tracking values, (2) on the basis

of the spectrum/Ltas/LPC display at the bottom part of

the Picture window, determine F1 and F2 by hand using

the Spectrum/Ltas/LPC in the Object window.

The script also puts in markers at H1, H2, A1, A2, A3, and

writes the values for H1-H2, H1-A1/2/3 to the Info window.

BY: Bert Remijsen

DATE: 28/09/2004

Modified by: the author of this paper (Summer, 2012)

form Calculate F1, F2, and intensity-related measurements for a specific segment

comment filename of inputlist (without extension .txt):

text listfile dur

comment list and files are located in dir:

text inputdir C:\Users\Jorge\Desktop\SLP\Dissertation\forGeorge\Mathon_choppedrecs

comment output files are written to input dir.

comment See header of script for details.

comment The label of segments to be measured, and the tier in the TextGrid:

word the_label n

integer the_tier 1

comment Select sex of speaker:

choice sex 1

button male

button female

```
  comment Length of window over which spectrogram is calculated:
  positive length 0.005
  comment Play sound?
  choice playit 1
  button yes
  button no
  comment Settings for Track... algorithm (MALE on the left; FEMALE on the right)
  positive left_F1_reference 500
  positive left_Transition_cost 1
  positive right_Transition_cost 1
  comment Carry out selective intensity measurements (H1, H2, A1, A2, A3):
  choice selective_intensity 1
  button yes
  button no
endform
Read Strings from raw text file... 'inputdir$'\'listfile$'.txt
end = Get number of strings
for fileteller from 1 to 'end'
 clearinfo
 counter = 0
 select Strings 'listfile$'
 file$ = Get string... 'fileteller'
 echo Processing 'file$', file 'fileteller' out of a total of 'end'
 Read from file... 'inputdir$'\'file$'.TextGrid
 textgrid = selected("TextGrid")
 textgridID = selected ("TextGrid", 1)
 Read from file... 'inputdir$'\'file$'.wav
 soundID = selected ("Sound", 1)
  positive right_F1_reference 550
  positive left_F2_reference 1485
  positive right_F2_reference 1650
  positive left_F3_reference 2475
  positive right_F3_reference 2750
  positive left_Frequency_cost 1
  positive right_Frequency_cost 1
  positive left_Bandwidth_cost 1
  positive right_Bandwidth_cost 1

 name$ = selected$ ("Sound")
 sound = selected("Sound")
 select 'textgrid'
 finishing_time = Get finishing time
 nlabels = Get number of intervals... 'the_tier'
  for label from 1 to 'nlabels'
  select 'textgrid'
  labelx$ = Get label of interval... 'the_tier' 'label'
  if (labelx$ = the_label$)
    counter = counter + 1
    n_b = Get starting point... 'the_tier' 'label'
    n_e = Get end point... 'the_tier' 'label'
    n_d = 'n_e' - 'n_b'
    n_md = ('n_b' + 'n_e') / 2
    call vowelq 'n_b' 'n_e' 'n_md' 'name$'
    if selective_intensity = 1
      call voiceq 'f1hzpt' 'f2hzpt' 'f3hzpt' 'name$'
    endif
  endif
  select 'textgrid'
```

```
   plus 'sound'

   endfor

endfor

procedure vowelq n_b n_e n_md name$

# set maximum frequency of Formant
calculation algorithm on basis of sex

# sex is 1 for male (left); sex is 2 for remale
(right).

 if 'sex' = 1

   maxf = 5000

  f1ref = left_F1_reference

  f2ref = left_F2_reference

  f3ref = left_F3_reference

  f4ref = 3465

  f5ref = 4455

  freqcost = left_Frequency_cost

  bwcost = left_Bandwidth_cost

  transcost = left_Transition_cost

 endif

 if 'sex' = 2

   maxf = 5500

  f1ref = right_F1_reference

  f2ref = right_F2_reference

  f3ref = right_F3_reference

  f4ref = 3850

  f5ref = 4950

  freqcost = right_Frequency_cost

  bwcost = right_Bandwidth_cost

  transcost = right_Transition_cost

 endif

 select 'sound'

 Resample... 16000 50

 sound_16khz = selected("Sound")

 To Formant (burg)... 0.01 5 'maxf' 0.025 50

 Rename... 'name$'_beforetracking

 formant_beforetracking = selected("Formant")

 Track... 3 'f1ref' 'f2ref' 'f3ref' 'f4ref' 'f5ref'
'freqcost' 'bwcost' 'transcost'

 Rename... 'name$'_aftertracking

 formant_aftertracking = selected("Formant")

# Get the f1,f2,f3 measurements.

 select 'formant_aftertracking'

 f1hzpt = Get value at time... 1 'n_md' Hertz
Linear

 f2hzpt = Get value at time... 2 'n_md' Hertz
Linear

 f3hzpt = Get value at time... 3 'n_md' Hertz
Linear

# display the formant tracks overlaid on
spectrogram.

  Erase all

  Font size... 14

  display_from = 'n_b' - 0.15

  if ('display_from' < 0)

    display_from = 0

  endif

  display_until = 'n_e' + 0.15

  if ('display_until' > 'finishing_time')

    display_until = 'finishing_time'

  endif

  select 'sound'

  To Spectrogram... 'length' 4000 0.002 20
Gaussian

  spectrogram = selected("Spectrogram")
```

```
  Viewport... 0 7 0 3.5

  Paint... 'display_from' 'display_until' 0 4000 100 yes 50 6 0 no

  select 'formant_aftertracking'

  Yellow

  Speckle... 'display_from' 'display_until' 4000 30 no

  Marks left every... 1 500 yes yes yes

  Viewport... 0 7 0 4.5

  select 'textgrid'

  Black

  Draw... 'display_from' 'display_until' no yes yes

  One mark bottom... 'n_md' yes yes yes

  rf1hzpt = round('f1hzpt')

  rf2hzpt = round('f2hzpt')

  rf3hzpt = round('f3hzpt')


  Draw... 0 3500 0 80 no bars

  Marks bottom every... 1 500 yes yes no

  Marks bottom every... 1 250 no no yes

  select 'sound_16khz'

  To LPC (autocorrelation)... 18 0.025 0.005 50

  lpc = selected("LPC")

  To Spectrum (slice)... 'n_md' 20 0 50

  Rename... LPC_'name$'

  spectrum_lpc = selected("Spectrum")

  select 'lpc'

  Remove

  select 'spectrum_lpc'

  Line width... 2

  Draw... 0 4000 0 80 no

  Text top... no Tracker output -- F1: 'rf1hzpt' ----- F2: 'rf2hzpt'

# display the spectrum, with Ltas and LPC

  select 'sound_16khz'

  spectrum_begin = n_md - 0.015

  spectrum_end = n_md + 0.015

  Extract part...  'spectrum_begin' 'spectrum_end' Hanning 1 no

  Rename... 'name$'_slice

  sound_16khz_slice = selected("Sound")

  To Spectrum (fft)

  spectrum = selected("Spectrum")

  Viewport... 0 7 4.5 8

  Draw... 0 3500 0 80 yes

  To Ltas (1-to-1)

  ltas = selected("Ltas")

  Viewport... 0 7 4.5 8


  Line width... 1

  Text top... yes Spectrum [30 ms], Ltas(1-to-1) [30 ms], LPC(autocorrelation), all three overlaid

echo Settings: F1ref:'f1ref' ---- F2ref:'f2ref' ---- F3ref:'f3ref' ---- F4ref:'f4ref' ---- F5ref:'f5ref' ---- Frequency cost:'freqcost' ---- Bandwidth cost:'bwcost' ---- Transition cost:'transcost'

endproc

procedure voiceq f1hzpt f2hzpt f3hzpt name$

 select 'sound'

 To Pitch... 0 60 350

 pitch = selected("Pitch")

 Interpolate

 Rename... 'name$'_interpolated

 pitch_interpolated = selected("Pitch")

 select 'pitch_interpolated'
```

```
  n_f0md = Get value at time... 'n_md' Hertz Linear

  rn_f0md = round('n_f0md')

  p10_nf0md = 'n_f0md' / 10

  select 'ltas'

  lowerbh1 = 'n_f0md' - 'p10_nf0md'

  upperbh1 = 'n_f0md' + 'p10_nf0md'

  lowerbh2 = ('n_f0md' * 2) - ('p10_nf0md' * 2)

  upperbh2 = ('n_f0md' * 2) + ('p10_nf0md' * 2)

  h1db = Get maximum... 'lowerbh1' 'upperbh1' None

  h1hz = Get frequency of maximum... 'lowerbh1' 'upperbh1' None

  h2db = Get maximum... 'lowerbh2' 'upperbh2' None

  h2hz = Get frequency of maximum... 'lowerbh2' 'upperbh2' None

  rh1hz = round('h1hz')

  rh2hz = round('h2hz')

# Get the a1, a2, a3 measurements.

  p10_f1hzpt = 'f1hzpt' / 10

  p10_f2hzpt = 'f2hzpt' / 10

  p10_f3hzpt = 'f3hzpt' / 10

  lowerba1 = 'f1hzpt' - 'p10_f1hzpt'

  upperba1 = 'f1hzpt' + 'p10_f1hzpt'

  lowerba2 = 'f2hzpt' - 'p10_f2hzpt'

  upperba2 = 'f2hzpt' + 'p10_f2hzpt'

  lowerba3 = 'f3hzpt' - 'p10_f3hzpt'

  upperba3 = 'f3hzpt' + 'p10_f3hzpt'

  a1db = Get maximum... 'lowerba1' 'upperba1' None

  a1hz = Get frequency of maximum... 'lowerba1' 'upperba1' None

  a2db = Get maximum... 'lowerba2' 'upperba2' None

  a2hz = Get frequency of maximum... 'lowerba2' 'upperba2' None

  a3db = Get maximum... 'lowerba3' 'upperba3' None

  a3hz = Get frequency of maximum... 'lowerba3' 'upperba3' None

# Calculate potential voice quality correlates.

   h1mnh2 = 'h1db' - 'h2db'

   h1mna1 = 'h1db' - 'a1db'

   h1mna2 = 'h1db' - 'a2db'

   h1mna3 = 'h1db' - 'a3db'

   rh1mnh2 = round('h1mnh2')

   rh1mna1 = round('h1mna1')

   rh1mna2 = round('h1mna2')

   rh1mna3 = round('h1mna3')

   if (playit = 1)

     select 'sound'

     Extract part... 'display_from' 'display_until' Hanning 1 no

     Play

     Remove

   endif

# display H1, H2, A1, A2, A3 of vowel to check for errors.

  Viewport... 0 7 4.5 8

  Font size... 14

  Line width... 2

  One mark bottom... 'h1hz' no no yes H1

  One mark bottom... 'h2hz' no no yes H2

  One mark top... 'a1hz' no no yes A1

  One mark top... 'a2hz' no no yes A2
```

```
  One mark top... 'a3hz' no no yes A3

  Line width... 1

  printline file 'file$'

  printline F0: 'rn_f0md' 'tab$' Frequency of H1: 'rh1hz' 'tab$' H1 (dB): 'h1db'

  printline 'tab$' Frequency of H2: 'rh2hz' 'tab$' H2 (dB): 'h2db'

  printline F1: 'rf1hzpt' 'tab$' Frequency of A1: 'a1hz' 'tab$' A1: 'a1db'

  printline F2: 'rf2hzpt' 'tab$' Frequency of A2: 'a2hz' 'tab$' A2: 'a2db'

  printline F3: 'rf3hzpt' 'tab$' Frequency of A3: 'a3hz' 'tab$' A3: 'a3db'

  printline H1-H2: 'h1mnh2:2'

  printline H1-A1: 'h1mna1:2'

  printline H1-A2: 'h1mna2:2'

  printline H1-A3: 'h1mna3:2'

  printline

  printline When the 'To formant' and 'Track...' procedures do not

  printline produce plausible formant values, the user can (1) run the

  printline script again with new tracking values, (2) on the basis

  printline of the spectrum/Ltas/LPC display at the bottom part of

  printline the Picture window, determine F1 and F2 by hand using

  printline e.g. the LPC (Spectrum LPC_slice) the Object window.

  printline

  printline

  fileappend 'directory$'\'outputfile$'

   fappendinfo 'output$.txt'

  select 'spectrum_lpc'

  pause ok? [occurrence 'counter' of segment 'the_label$']

  select 'spectrum_lpc'

  plus 'spectrum'

  plus 'spectrum'

  plus 'ltas'

  plus 'spectrogram'

  plus 'formant_beforetracking'

  plus 'formant_aftertracking'

  plus 'sound_16khz'

  plus 'sound_16khz_slice'

  plus 'pitch'

  plus 'pitch_interpolated'

  Remove

endproc
```

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