Linguistic Portfolios

Volume 6 | Article 12

2017

The New Paradigm in Tone Analysis: The Contribution of the Critical Band Theory

Ettien Koffi
St. Cloud State University, enkoffi@stcloudstate.edu

Linguistic Portfolios–ISSN 2472-5102 –Volume 6, 2017 | 147

THE NEW PARADIGM IN TONE ANALYSIS: THE CONTRIBUTION OF THE CRITICAL BAND THEORY

ETTIEN KOFFI

ABSTRACT

The vast majority of African linguists still rely on their naked ears to determine pitch registers and tone rules. In recent years, timid efforts have been made by some to complement their impressionistic analyses with acoustic phonetic measurements. Yet, they still interpret the acoustic data impressionistically. In this paper, I propose a new approach based on the Critical Band Theory (CBT). This theory was pioneered by Physicist Harvey Fletcher who postulated on the basis of mathematical calculations that the basilar membrane compartmentalizes speech signals into frequency bands. He demonstrated this in various experiments that culminated in his seminal paper, Auditory Patterns (1940). Seven years later, von Békésy, another physicist, published The Variations of Phase along the Basilar Membrane with Sinusoidal Vibrations in which he proved clinically that Fletcher's theory was grounded in physiological reality. There are three main advantages in using CBT to study pitch registers and tone rules in African languages. First, it correlates F0 measurements directly with a pre-existing critical band template. Therefore, pitch registers are determined independently of the researcher's pre-conceived ideas about pitch levels. Secondly, the findings are authoritative because the critical band system has been endorsed by the American National Standards Institute (ANSI), the International Standardization Organization (ISO), and the International Electrotechnical Commission (IEC) for designing and manufacturing audio products and sound level meters. Last but not least, CBT-based findings are falsifiable and applicable to all tone languages.

1.0 Introduction

There used to be a time when the mere mention of tone inspired fear and awe among would-be students of African languages (Welmers 1973:77). Those days are long gone. We now live in an era when anyone who has taken one or two courses in phonology feels eminently qualified to prognosticate about pitch registers and tone rules in African languages. Conference papers and publications of all sorts abound on African tone languages. These writings seem to have one thing in common: they paint a very complex picture of tone rules that often defy logic. In some quarters, the quality of a paper or a presentation is judged by the insuperable complexity of the tone rules. There is, however, a problem with many of these analyses. They are all too often based on the author's own ability to detect pitch registers with his/her naked ears, an approach that Ladefoged considers out of date (Fromkin 1985:7). Now some researchers are trying to bolster their impressionistic claims with acoustic measurements but even these attempts are fraught with problems because analysists still interpret the acoustic data through impressionistic lenses. In this paper, I am proposing a new paradigm for studying tone registers and tone rules in African languages. It is presented in six stages. The first relates my personal frustrations with tone analyses in West African languages, the second highlights the pitfalls of studying tone impressionistically, the third assesses the attempts that have been made to incorporate acoustic measurements in analyses of tones, the fourth provides an overview of tone registers in world languages, the fifth introduces the Critical Band Theory (CBT), and the sixth illustrates how CBT can be used to study pitch registers of Anyi verbs.

2.0 My Frustrations with Tones

The quest for a new paradigm stems from many years of frustration in my attempts at finding an optimal system to indicate tone in the orthography of African languages. Right after earning my Ph.D. in linguistics, I was appointed by the United Bible Societies as a translation consultant in Benin and Togo. In this capacity, I oversaw 12 Bible translation projects. Most of the projects dealt with the Old Testament. Even though the New Testament had been translated into most of the languages under my supervision, I quickly noticed that the translators and literacy workers could not randomly pick up a text and read it. Their plight was due to the fact that tone was not indicated in their New Testaments.[1] Their situations were analogous to the one that Welmers (1973:118) describes for Bassa:

> It has proven far too easy to underestimate the importance of indicating tone. In recording a Bassa (of Liberia) reading of a portion of the Bible for broadcast purposes, it was noted that, no matter who the reader was, he could only read one sentence at a time; for each sentence, he had to experiment with various combinations of tone before settling on a combination that seemed the most reasonable.

The translators told me that for Scripture reading during church services on Sundays, they would assign the text to would-be readers two or three days ahead of time. This way, the person would have plenty of practice before reading it out loud in front of the congregation. Otherwise, the reading would be a mess. My desire to design orthographies for these languages and for Anyi, my native language, led me deeper and deeper into physics, into acoustic phonetics, and eventually to the Critical Band Theory (CBT), which will be described in detail in 5.0. I realized rather quickly that the impressionistic way of doing tone analysis was woefully inadequate for reasons to be described below.

3.0 The Pitfalls of Studying Tone Impressionistically

The impressionistic method, that is, relying solely on one's own aural pitch perception abilities, is by far the most widespread approach that linguists have used and continue to use to describe African tone languages. Even in such an influential book as *Tone: A Linguistic Survey,* edited by Victoria Fromkin in 1978, the analyses in 8 of the 11 papers are based on the impressionistic method. The three papers that use an instrumental approach are Ohala's *Production of Tone*, Gandour's *Perception of Tone*, and Hombert's *Consonant Types, Vowel Quality, and Tone*. There are serious pitfalls when researchers rely solely on their own hearing abilities to describe pitch registers and tone rules. Several important studies have shown that people's ability to detect pitch varies drastically. Houtsma (1995:282, 288) who has studied pitch perception extensively, groups people into three categories. Those with innate abilities can perceive pitch perfectly: "The possessors of *genuine* absolute pitch typically make quick absolute identifications, accurate within a semitone, with octave confusions being the principal source of errors." He is quick to add that people with this ability are hard to find. The second group is made up of people who acquire good pitch perception abilities through training. Included in this group are "orchestra musicians" and "vocal range singers." He notes that their ability develops over time, and "given enough time, these subjects can make fairly accurate absolute pitch

[1] I describe this situation in depth and the solutions that I proposed to remedy the problems in Koffi (2012:225-232).

judgments, but if forced to respond quickly they will typically make large errors." The last category includes the vast majority of humans, that is, people who are by and large tone deaf.[2] It goes without saying that having a Ph. D. in linguistics is not prima facie evidence that one can perceive pitch registers accurately. As a matter of fact, even the famed Peter Ladefoged, the leading phonetician of the second half of the 20th century, had problems perceiving pitch accurately. He said so himself: "I've never been very good at transcribing tones. … I've always found it hard to give good descriptions of subtle changes in pitch," (Ladefoged 2003:75). He also gave the following piece of advice to researchers: "When working on tone languages, don't expect too much help from native speakers. Some may be able to tell whether the pitch of the voice rises or falls during a given word, but many cannot. As far as they are concerned, two words differing in tone just sound different, and they may be no more able to say how they differ than most speakers of English can tell how *head* and *hid* differ" (Ladefoged 2003:81). The inability for most native speakers to perceive pitch accurately is not limited to speakers of tone languages. Fry (1955:765) says the same about native speakers of English, "It is not always easy for listeners, especially untrained listeners, to judge where the stress or accent falls in a particular word." In a nutshell, the vast majority of people, including linguists, are tone deaf.[3] Consequently, one cannot rely solely on impressionistic assessments of pitch registers and tone rules to design optimal orthographies for African tone languages. Instrumental means are an absolute necessity.

4.0 Instrumental Complement to Impressionistic Analyses of Pitch

Ladefoged (2003:27) tells the following story that highlights the need to complement impressionistic analyses with acoustic phonetic data:

> When Daniel Jones, the greatest phonetician of the first part of the twentieth century, was setting out on a fieldwork trip, a reporter asked him, 'Professor Jones, what instruments are you taking with you?' He pointed to his ears and said, 'Only these.' There is no doubt that the ultimate authority in all phonetic questions is the human ear. But nowadays instrumental aids can often illuminate particular points, acting like a magnifying glass when we need to distinguish two similar sounds.

In an interview-style paper that Fromkin (1985:7) wrote in honor of Ladefoged, the same story is recounted, with the following statement, "…but today, anybody who relies simply on ears is out of date. There are so many things you can find out with experimental techniques and new instruments." An infinitesimal fraction of researchers on African tone languages complement their impressionistic analyses with instrumental data. Those who do use instruments still interpret the acoustic measurements through the lenses of their pre-conceived impressionistic ideas of pitch registers instead of letting the acoustic data speak for itself. This superposition leads to paradoxical results, as is the case in the four examples cited below.

---

[2] Readers who wish to assess how well they can perceive F0 can take the Cool Hearing Test for free at https://www.youtube.com/watch?v=h5l4Rt4Ol7M. Retrieved on January 31st, 2017.

[3] I urge those who do research on tone languages, especially African tone languages, to take the pitch perception test.

The first example is from Quaireau's (1978:170) analysis of Anyi tone rules. We focus only on the pitch register on the word /sʊ/ produced by Male 1 and Male 3 in the following sentences:

Male 1:	[ɔ̀	sʊ́	kɔ̀	bɛ́	kùló	lɔ̀]
	110	130	110	120	100/105	95

Male 3:	[ɔ̀	sʊ́	kɔ̀	bɛ́	kùló	lɔ̀]
	130	190	120	160	120/140	130

In Male 1's speech, the vowel of [sʊ́] has an F0 of 130 Hz. Its pitch is described as high. In Male 3's speech, the F0 of [sʊ́] is 190 Hz. It is also described as high. Now, let's consider the pitch of [ɔ̀] produced by Male 3 at the beginning of the sentence. Its F0 is 130 Hz. Yet, it is described as low. If the F0 of [ʊ́] in [sʊ́] produced by Male 1 is high, why isn't the pitch of [ɔ̀] also high? How can an F0 of 130 Hz of one vowel be high, but the same F0 be low for another vowel? Ultimately, who decides when a given F0 is high or low?

The second example is found in Rivera-Castillo and Pickering (2004:273). Here, we focus on the pitch of the words [ké] and [piská] produced three times by the same female talker:

First repetition:	[mi	ké	piská]
		239	216/256
Second repetition:	[mi	ké	piská]
		225	216/193
Third repetition:	[mi	ké	piská]
		225	190/172

In the second repetition, the pitch of [é] is 225 Hz and it is labeled low. In the third repetition, it is also 225 Hz, but this time it is labeled high. How can an F0 of 225 Hz be high in one instance and low in another? Again, who decides when a given F0 is high or low?

The third example is taken from Hogan (1998:76). The analysis focuses on the pitch of [ɛ̀] at the beginning of the sentence, and [á] at the end of the sentence:

Sentence 1:	[ɛ̀	táwá	cé	tíná]
	100	135/135	130	130/90

The F0 of the sentence-initial [ɛ̀] is 100 Hz. Its pitch is marked as low. The F0 of the vowel [á] at the end of the sentence is 90 Hz. Yet, it is marked as having a high pitch. In what mathematical universe is 100 Hz lower than 90 Hz?

The final example is from Downing (2008:62). Her data is slightly different from the others, but it serves to illustrate the confusion surrounding pitch registers. Granted that Downing does not focus on the F0 of individual vowels, but on the mean pitch of the whole phrase. In her article, she is describing the use of F0 to encode discourse focus. She notes on page 61 that "focus leads to systematic raising of F0 within the Phonological Phrase containing the focused element." She provides three examples to illustrate how focus works:

Sentence 6c: A-ná-méy-a nyuúmba **ndí nwáálá**↑
120

Sentence 6d: A-ná-méy-a **nyuúmba**↑ ndí nwáálá
134.4

Sentence 6e: **A-ná-méy-a**↑ nyuúmba ndí nwáálá
179.0

Downing uses the IPA diacritic "↑" to show that the highlighted words are in focus. There are issues with the acoustic measurements that she provides to support her claim of "systematic raising of F0" when elements are in focus. Consider the F0 of the highlighted elements in Sentences 6c and 6e. Both are considered in focus even though the F0 difference between them is 59 Hz. Similarly, the F0 difference between the elements in Sentences 6d and 6e is 44.6 Hz. Now, consider the differences between the highlighted words in 6c and 6d. The F0 difference between them is only 14.4 Hz. How can the highlighted words in these three sentences be all equally raised despite the varying degrees of F0 differences between them?

These four examples highlight a fundamental flaw in the various correlations between acoustic measurements and pitch levels. The correlations appear arbitrary, unsystematic, and random. Each researcher correlates whichever acoustic measurement willy-nilly with whichever pitch level without any rhyme or reason. The accuracy of the acoustic measurements is not in doubt. What is in doubt is the interpretation of the acoustic measurements relative to pitch levels. What good is an instrumental analysis if its results are interpreted according to pre-conceived impressionistic grids instead of letting the data speak for itself? Let me be crystal clear and state emphatically that the problems do not lie with the linguistic abilities of the four researchers whose data I have reviewed in this paper. They are competent linguists in their own right. Downing's knowledge of the tone systems of southern African languages is incredible and her publications on tone are extensive and well respected. The problems with the correlations between F0 measurements and pitch levels stem from the fact that linguists for the most part are unaware of the breakthrough research that has been done in physics, acoustics, and psychoacoustics over the last 50 years or more about frequency detection and perception.[4] These problems prove that Lehiste (1970:vi) was right in saying that "a phonologist ignores phonetics at his own peril." She explains what she meant at the end of her book:

> Linguistics is an empirical science. As such, it describes observed linguistic facts, seeks to explain them, and attempts to set up predictions. The validity of the predictions and explanations depends in a very real way upon the correctness of observations. A comparison of predictions with actual realizations provides the ultimate test of the

[4] According to http://acousticalsociety.org/membership, only 3.4% (225 out of 6620 respondents) of the members of the Acoustical Society of America (ASA) self-identify as linguists. Overall, 0.2% of ASA members (13 people) are from Africa. None of these 13 members of the ASA may be linguists. They may be physicists, acousticians, engineers, biologists, etc. I do not personally know any African linguist who is a member of the ASA. Information retrieved on February 5, 2017.

> correctness of the predictions. Phonetic realizations of utterances are the only aspect of the language directly subject to observation; and experimental phonetics provides a point at which linguistic theories can be tested with respect to at least one kind of objective reality. The desire for such verification has provided the motivation for the quest for phonetic reality to which this book owes its existence (Lehiste 1970:168).

A similar motivation is behind this article. The quest for phonetic reality leads me to re-analyze the data discussed in this section in light of CBT. The analysis will reveal that the correlations between pitch and acoustic measurements are paradoxical because the four linguists interpreted their F0 data impressionistically.

5.0 A Brief Overview of the Critical Band Theory

In 1940, Physicist Harvey Fletcher, who is also credited with the invention of the modern audiogram machine, wrote a paper entitled *Auditory Patterns*. In it, he postulated on the basis of mathematical calculations that the basilar membrane compartmentalizes speech signals into frequency band filters. He demonstrated this in various experiments described in his seminal paper. Seven years later, Békésy, another physicist, published *The Variations of Phase along the Basilar Membrane with Sinusoidal Vibrations*. In this groundbreaking paper, he proved clinically that Fletcher's findings were grounded in physiological reality. This discovery earned Békésy a Nobel Prize in medicine in 1961. The view that specific areas of the basilar membrane perceive specific frequencies has given birth to a theory called Critical Band Theory, or CBT. The human auditory spectrum that ranges from 20 to 20,000 Hz has been subdivided into some 30 critical bands (Pope 1998:1347). Zwicker (1961:248) explains the usefulness of this subdivision as follows:

> The subdivision of the frequency range over which the human ear is able to perceive tones and noises is often desirable for the handling of various problems. For mathematical and physical purposes it is useful to divide the scale either linearly or geometrically (logarithmically) as, for example, into octave and third-octave. Some problems, on the other hand, call for a subdivision more closely related to the manner in which the ear itself appears to carry out the process. Here the subdivisions into critical bands seems to be very useful.

The proposed subdivisions into octave and third-octave have been endorsed by the American National Standards Institute (ANSI), the International Standardization Organization (ISO), and the International Electrotechnical Commission (IEC). They satisfy the requirements that

> … the numerical values of the parameters measured be in reasonable agreement with the subjective impression of sound phenomena. Furthermore, the instrumentation developed for the measurement of these parameters must be accurate to provide consistent values for comparison of results from workers and measurement sites (Bruel et al. 1998:1313).

The subdivision of the audibility range into critical bands is used in designing and manufacturing audio engineering products and sound levels meters worldwide. It is important to emphasize here that these subdivisions apply to all and reflect how all human beings process acoustic signals. Figure 1 gives us a rough idea of the areas of the basilar membrane where specific frequencies are perceived.

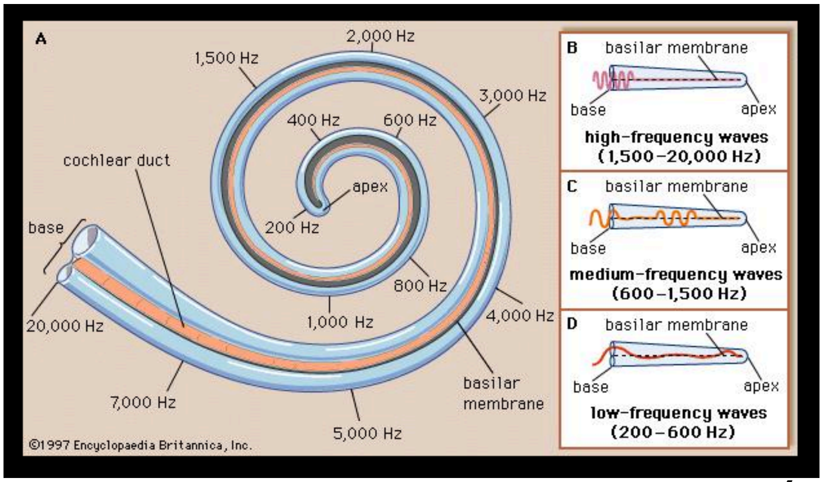

Figure 1: Subdivisions of the Basilar Membrane into Frequency Bands[5]

The basilar membrane is encased inside the cochlea and varies in length from 3.2 to 3.5 cm. It has more than 16,000 sensory receptors called hair cells. The information in Figure 1 justifies why the cochlea has been nicknamed "the frequency analyzer of the auditory system." Von Békésy's experiments indicate that each critical band is approximately 1.3 mm long. This explains why there are approximately 30 critical bands. However, Hansen (2001:29) cautions that the anatomical subdivisions and the critical band subdivisions do not match perfectly, even though they come very close. [6]

5.1 The Basilar Membrane, Critical Bands, and the Octave System

The octave is the unit of measurement into which the auditory spectrum is subdivided. It is a word of Latin origin that means "eight". For some calculations, the auditory system is divided into eighths, but according to Everest and Pohlmann (2015:529), Pope (1998:1346), and others, the third-octave subdivision is the best because "it approximates the critical bandwidth accuracy of our hearing." Each third octave is further subdivided into lower band limits, upper band limits and center frequencies, as shown in Table 1. For pitch perception, there are six critical bandwidths. The information contained within each one is perceived identically, regardless of whether they are in the lower band limits, in the center frequency, or in the upper band limits. The reason for this is because frequency is perceived logarithmically, not arithmetically. This means that an F0 of 71 Hz is perceived as having the same pitch as an F0 of 87 Hz. Fry (1958:141) explains, "In the intonation patterns heard from most English speakers changes in pitch of more than one octave are infrequent and are not often met in successive syllables, even from excitable speakers." He also notes that in perceiving F0, the magnitude of the variation within the same critical band does not matter so long as a pitch change is detected.

---

[5] Source: http://www.britannica.com/science/ear/images-videos/The-analysis-of-sound-frequencies-by-the-basilar-membrane/537.

[6] The number of critical bands varies from 25 to 30, depending on the length of one's basilar membrane.

N0	Lower Band Limits	Center Frequency	Upper Band Limits
1.	71	80	88
2.	88	100	113
3.	113	125	141
4.	141	160	176
5.	176	200	225
6.	225	250	283

Table 1: Low Frequencies in the One-Third-Octave Band

Multiple pitch perception studies have confirmed that F0 data is perceived towards the apex of the basilar membrane, that is, in the area below 500 Hz (see Figure 1). Moerel et al. (2012:14212) used fMRI imaging to have a clear idea of the processing of frequencies in the auditory cortex. They concluded that it "responds more strongly to low-frequency tones than middle and high frequency tones." Ritsma (1967:197) indicates that pitch perception is optimal in the 100 to 400 Hz frequency range. Palmer (1995:105), Grantham (1995:328), and Darwin and Carlyon (1995:388), to mention only a few, have all reached a similar conclusion. It is worth noting that the default settings of F0 in Praat range from 75 to 500 Hz. Nearly all speech analysis software packages have identical default settings. The minimum is at 75 Hz because this is the threshold at which an average adult with normal hearing can perceive pitch. The maximum is at 500 Hz even though in naturally occurring speech, adults do not produce F0 beyond 400 Hz. However, it is good to keep the maximum at 500 Hz just in case one wants to study the high- pitched cries of colicky babies, as is done in pediatric acoustics.

5.2 Correlating Critical Bands with Tone Registers

In the remaining sections, we correlate the critical bands in Table 1 with pitch registers and use this information to support the new paradigm in tone analysis that we are proposing. We begin the analysis with statements about pitch registers that most linguists accept as uncontroversial. Anderson (1978:167-172) notes that most researchers agree on systems with five pitch registers (levels) in tone languages. This subdivision is endorsed by the International Phonetic Association (*The Handbook of the IPA* (1999:14). The five pitch levels are:

- Extra low
- Low
- Mid
- High
- Extra high

Maddieson (1978:338-40) has proposed the following generalizations on the basis of these five pitch registers:

1. A language may contrast up to five levels of tone, but no more.
2. Languages with three tone levels are commonplace, while those with only two are the most frequently encountered type of tone language.
3. Pitch intervals are measured in Hz between tone levels.
4. Phonetically central tones are unmarked, extreme tones are highly marked.

Linguistic Portfolios–ISSN 2472-5102 –Volume 6, 2017 | 155

5. Extra High and Extra Low do not normally occur unless there are additional tone levels in between.

Anderson (1978:169) quotes Pike as saying that "all tone languages use essentially the same pitch range, subdividing it into as many registers as required by their tone systems." This underscores the view that the subdivisions of the auditory spectrum into third octave frequency bands works for every human language. In other words, CBT is applicable to the analysis of all tone languages.

Let's now correlate the third octave frequency bands data in Table 1 with the five pitch registers mentioned above and combine them into a single table, as shown in Table 2:

N0	Tone Registers	Lower Limits	Center Frequency	Upper Limits	Range
1.	Extra low	71	80	88	17 Hz
2.	Low	88	100	113	25 Hz
3.	Mid	113	125	141	28 Hz
4.	High	141	160	176	35 Hz
5.	Extra high	176	200	225	49 Hz

Table 2: Critical Bands for Men

Table 2 provides us with a principled way of correlating F0 measurements with pitch levels. In this CBT-based approach, the determination as to whether an F0 measurement corresponds to a low, mid, or high pitch no longer depends on the impressionistic assessment of the analyst, but rather on a pre-established tone and frequency template. Let's now use this template to re-evaluate the data discussed in 4.0.

We begin with Quaireau's (1978:170) data on Anyi reproduced below. A CBT-based analysis shows that the pitch of [sʊ́] (130 Hz) produced by Male 1 and that of [ɔ] (130 Hz) by Male 3 should be interpreted identically as mid, since they have the same F0 values. Moreover, we see clearly that the pitches of [sʊ́] by Male 1 (130 Hz) and by Male 3 (190 Hz) do not have the same pitch register. The former is mid, while the latter is extra high pitch.[7] Quaireau assigned the same pitch level to both items based on his pre-conceived impressionistic view that the morpheme [sʊ́] has a phonemic high pitch. In so doing, he disregarded the acoustic measurements and interpreted the data impressionistically.

Male 1:	[ɔ̀	sʊ́	kɔ̀	bɛ́	kùló	lɔ̀]
	110	130	110	120	100/105	95

Male 3:	[ɔ̀	sʊ́	kɔ̀	bɛ́	kùló	lɔ̀]
	130	190	120	160	120/140	130

A CBT-based re-analysis highlights the inherent contradiction in Hogan's (1998:76) interpretation of the pitch registers of [ɛ̀] (100 Hz) and [á] (90 Hz) of [tíná] in Sentence 1

[7] This talker is a man of small frame and a heavy smoker. Both factors increase F0 in males (Traunmuller and Eriksson, p. 4). Frequencies of this level are characteristic of female talkers. If his F0 is normalized according to female frequencies, then the pitch of [sʊ́] is mid. See 5.3 for the discussion of female F0s.

reproduced below. There is a paradox here because, though the F0 of [ɛ̀] is higher than [á], he assigns a low pitch to the former and high pitch to the latter.

Sentence 1:	[ɛ̀	táwá	cé	tíná]
	100	135/135	130	130/90

In reality, both pitch registers are low because they fall inside of the same octave and the same bandwidth. Though they have different numerical values, the ear interprets them identically because frequency is perceived logarithmically, not arithmetically.

A CBT-based analysis provides a better explanation for why the highlighted phonological phrase in Sentence 6C is "raised." Normally, in declarative sentences, there is a downdrift rule in many languages. Since the phrase occurs at the end of an utterance, we expect its F0 to be 88 Hz or lower. However, in this case, we have an F0 of 120 Hz, which correlates with a mid pitch register. This supports Downing's (2008) claim that focus leads to pitch raising of phonological phrases.

Sentence 6c: A-ná-méy-a nyuúmba **ndí nwáálá**↑
120
Sentence 6d: A-ná-méy-a **nyuúmba**↑ ndí nwáálá
134.4
Sentence 6e: **A-ná-méy-a**↑ nyuúmba ndí nwáálá
179

The CBT analysis of the pitch of the phonological phrases in Sentences 6c and 6d does not show that there is any perceptual difference between the two utterances. The ear perceives both sentences identically because, though there is a difference of 14.4 Hz between them, this F0 difference is less than 20 Hz. Humans cannot perceive a frequency difference of less than 20 Hz within the same 1/3 octave bandwidth, as indicated in Table 2. The CBT analysis predicts rather accurately that the pitch register of the phonological phrases in both utterances is mid. Since the highlighted phonological phrase occurs inside a sentence, it is doubtful that it qualifies as "raised." In my considered opinion, it has a default intonation. Finally, a CBT-based analysis supports Downing's observation that focus has taken place in Sentence 6e. Its F0 of 179 Hz correlates with an extra high pitch.

The new approach that I'm proposing provides a clearer explanation of pitch levels and intonation patterns. We see that it has resolved the contradictions found in Quaireau's and in Hogan's correlations between F0 measurements and pitch registers. It also clarifies Downing's use of the term "raised" in reference to focus. Her usage of this term is unclear because "raised" does not correspond with any known pitch level. In acoustic phonetics terminology, the pitch of the phonological phrase in Sentence 6c is mid, while that of Sentence 6e is extra high. Perceptually, the pitches of Sentences 6c and 6d are indistinguishable because they are on the same octave band and also because the difference between them is less than 20 Hz.

5.3 CBT and Gender Differences in Pitch Production and Perception

The F0 data that we have analyzed so far are produced by male speakers. CBT makes it possible to also analyze data produced by female talkers. Nearly all available data on pitch shows clearly that males and females have different pitch values. Miller (1989:2122) reports that the average F0 for men is 133 Hz, while that for women is 225 Hz. Fry (1979:68) has 120 Hz for men, and 225 Hz for women. Data available from Peterson and Barney (1952) indicates that the F0 for males is 132 Hz and that for females is 223 Hz. We find similar numbers in Hillenbrand et al. (1995): 130 Hz for males and 230 Hz for females. Stevens (1998:1232) does not focus on mean F0 values, but rather on the range of variation for females, males, and children. He writes:

> The frequency of vibration of the vocal folds during normal speech production is usually in the range of 170-340 Hz for adult females, 80-160 Hz for adult males, and 250-500 Hz for younger children. The frequencies can extend well beyond these ranges for the singing voice."

The pitch differences are grounded in the anatomical differences between the larynxes of males and females. Stevens (2000:6,8,25) reports that on average the length of the vocal folds in adult males is 1.5 cm, whereas it is 1.0 cm in females. The vocal tract length is 16.9 cm in adult males versus 14.1 cm in females. The pharynx is also longer in males (8.9 cm) than in females (6.3 cm). Finally, the size of the oral cavity varies from 8.1 cm in males to 7.8 cm in females. Proponents of the Source Filter Theory rely on differences such as these to account for why males and females sound different. With regard to pitch, the 0.5 cm difference in the length of the vocal folds is primarily responsible for why females have a higher F0 than their male counterparts.

When using CBT to determine pitch registers, we have to factor in gender-based anatomical differences. The default in most studies is male F0s. To estimate female F0s on the basis of male data, it is recommended that male data be adjusted upward by 50%.[8] This is what we have done in Table 3:

N0	Tone Registers	Lower Limits	Center Frequency	Upper Limits	Range
1.	Extra low	106	120	132	26 Hz
2.	Low	132	150	169	37 Hz
3.	Mid	169	185	211	42 Hz
4.	High	211	240	264	53 Hz
5.	Extra high	264	300	337	73 Hz

Table 3: Critical Bands for Women

Let's now apply CBT to re-analyze Rivera-Castillo and Pickering's (2004:273) data reproduced below. They note on page 270 that they collected their data from an Aruban female college student in her twenties.

First repetition:	[mi	ké	piská]
		239	216/256

[8] Quaireau (1978:129) uses the same formula in normalizing the F0s of female participants. The data from American English indicates that the formula should be about 56%. However, one would not go wrong with 50%.

Second repetition:	[mi	ké	piská]
		225	216/193
Third repetition:	[mi	ké	piská]
		225	190/172

A CBT-based analysis shows that the F0 of the second repetition of [ké] (225 Hz) corresponds to a high tone, not just the third repetition, as reported by Rivera-Castillo and Pickering. Given two identical F0 measurements, why would one have a high pitch and the other a low pitch? An analysis such as the one proposed by Rivera-Castillo and Pickering does not make any sense. CBT converts F0 measurements into pitch register scales systematically and consistently. It helps avoid the paradoxical conclusions that ensue when one interprets F0 data impressionistically.

6.0 Application to Anyi Tones

In this section, the insights of CBT are applied to analyze pitch registers of Anyi verbs conjugated in the imperative mood. Before delving into the data, we must first give a quick overview of the language and its tonal structure. Anyi belongs to the Akan family of languages that stretch from eastern Côte d'Ivoire to western Ghana. In Côte d'Ivoire, more than a million people (1,072,618) speak Anyi, which is subdivided into seven main dialects. Seventy-five percent of all Anyi people speak the Morofu dialect (804,000).[9] Four participants from that dialect in the Bongouanou prefecture, the main administrative center of the Moronou region, took part in this study. They are bilingual in Anyi and French and work as literacy teachers for CATA (the Anyi Literacy and Translation Center), a non-governmental organization dedicated to adult literacy in the Anyiland. The participants, who are all males, range in age from 30 to 50. The elicitation task consisted of two sets of data: two monosyllabic verbs, /dí/ (to eat), /kɔ́/ (to go); and two disyllabic verbs, /bʊ̀ká/ (to help), and /sìké/ (to host).

6.1 Instruments and Methods

The four male participants were recorded on an Olympus Digital Voice Recorder WS-710. They wore a Panasonic head-mounted, noise cancellation fixed microphone in order to minimize environmental noise. The recording took place in a quiet room in 2012. Approval to record the data was granted by the Institutional Review Board (IRB) of Saint Cloud State University in MN, USA. All the participants willingly signed the informed consent form. WavePad Sound Editor, Version 5.17 by NCH Software was used to sample all the files at 44100 Hz at the rate of 16 bits per sample. File segmentation and editing were done through WavePad, but the measurements of the data were collected via Praat. Ryan's (2005) Grid-maker script for Praat was used to semi-automate the segmentation system. The calculations of the means and standard deviations were done in Excel. The annotation procedure is shown in Figure 2:

[9] These figures are projections based on the official data from the 2000 census. It takes into account an overall 3% annual population grown in Côte d'Ivoire.

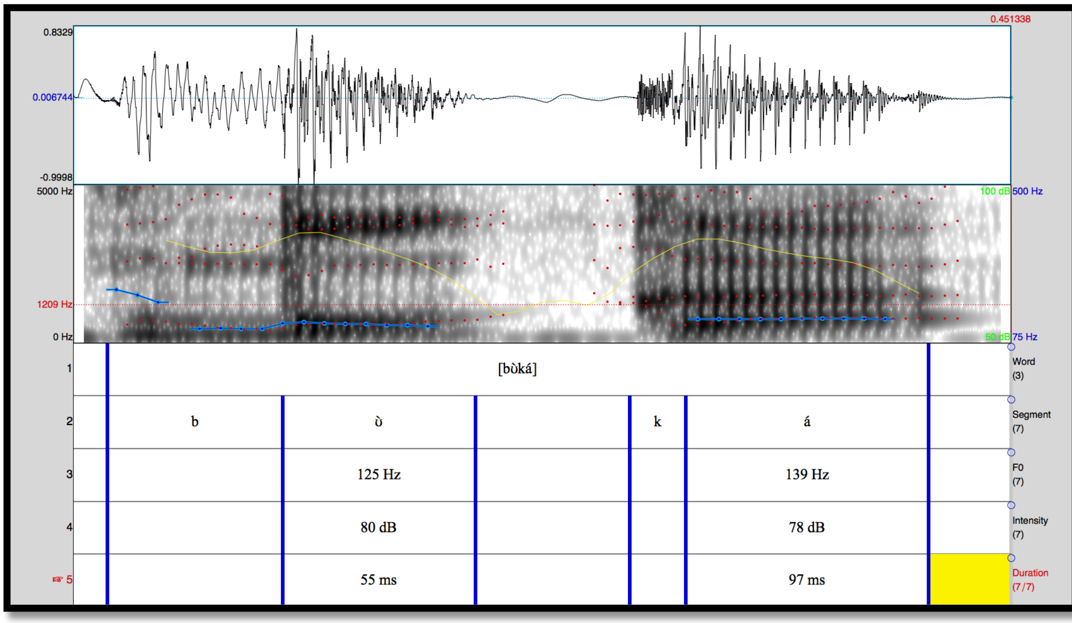

Figure 2: Sample Annotate Spectrograph

Though the acoustic correlates of F0, intensity, and duration were collected, only F0 is discussed in this paper. Duration and intensity measurements are in the appendix. They are important acoustic correlates of tone, but they are not directly relevant to the points being made in this paper.

6.2 A CBT-based Analysis of Pitch Register on Verbs

There is a longstanding tradition in African linguistics that, in many languages, one can determine the underlying tone (also known as phonemic tone) of verbs by producing them in isolation (Welmers 1973:140) or conjugating them in the imperative mood (Hyman 2010:186). In Anyi and also in Baule, the base form of verbs in the imperative is conjugated in the 2nd person singular. Quaireau (1987:276), Burmeister (1983:170-1), and Creissels and Kouadio (1977:5234-5, 377) have reported that monosyllabic verbs have a high tone (CV́), while disyllabic verbs have a low tone on the first vowel, and a high tone on the last one (CV̀CV́). It is worth noting that their findings about pitch registers are based on impressionistic analyses. As a result, their results may differ from the acoustic measurements in Table 4:

Words	/dí/	/kɔ́/	/bʊ̀ ká/		/sì ké/	
F0/Pitch in Hz	[i]	[ɔ]	[ʊ]	[a]	[i]	[e]
Speaker 1	116	114	109	116	108	110
Speaker 2	147	148	89	107	113	130
Speaker 3	207	148	125	139	153	179
Speaker 4	147	105	81	139	94	103
F0 Mean	**154**	**148**	**101**	**125**	**117**	**130**
St. deviation	38	22	19	16	25	39
Phonemic Pitch	CV́	CV́	CV̀	CV́	CV̀	CV́
Phonetic Pitch	CV́	CV́	CV̀	CV̄	CV̄	CV̄

Table 4: Pitch of Monosyllabic and Disyllabic Verbs in the Imperative Mood

The instrumental and the impressionistic analyses agree that the pitch register of monosyllabic verbs is high. The F0 of [í] (154 Hz) and that of [ɔ́] (148 Hz) correspond to a high pitch tone on the CBT scale. However, there is no consensus on the pitch levels for disyllabic verbs such as /bʊ̀ká/ and /sìké/. The F0 of [bʊ̀] is 101 Hz, which is low, but the pitch of [kā] (125 Hz) is mid, not high. As for /sìké/, the pitch of [ī] (117 Hz) is mid and that of [ē] (130 Hz) is also mid. The predicted CV̀CV́ tone pattern on disyllabic verbs does not seem to hold. Instead, we have a CV̀CV̄ or CV̄CV̄ pattern. The sample is too small. Consequently, I do not claim that it invalidates the impressionistic findings; yet we acknowledge that there is a discrepancy. We also note that Creissels and Kouadio (1977:234-5, 377) transcribed two disyllabic Baule verbs conjugated in the imperative mood as having mid tone. The words in question are [dʒàsō] (stand up) and [mīndā] (tie). Their pitch registers have a CV̀CV̄ or CV̄CV̄ patterns, just as we have in Anyi.[10] They explain these departures from the canonical CV̀CV́ pitch pattern by alleging that when disyllabic verbs are produced, even in their citation forms, a phonological rule applies that lowers high tones to mid. This ill-defined rule may be responsible for why /bʊ̀ká/ is realized [bʊ̀kā], and /sìké/ becomes [sīkē].

6.3 The Intrinsic Value of Vowels and Pitch

The pitch-lowering rule that Creissels and Kouadio (1977:58) have in mind is still unclear to me. However, it is well known in acoustic phonetics that pitch levels may be affected by the intrinsic F0 values of individual vowels. Lehiste (1970:128) took Bolinger (1958) to task for not taking these intrinsic values into account in his analysis of English stress patterns. I'd be remiss if I failed to highlight the F0 of individual vowels in Anyi that could potentially affect pitch registers and tone rules. The intrinsic F0 of Anyi vowels displayed in Table 5 are from Koffi (2016:124). These intrinsic pitch values are displayed alongside Peterson and Barney (1952) and Hillenbrand et al. (1999) to show that similar research has been undertaken in American English.

[10] Anyi and Baule are so close they may be seen as dialects of the same language. Some see them that way, but others contend that they are two separate languages (McWhorter 2003:78). For me, Anyi is as different from Baule as American English is from British English.

Correlates	[i]	[ɪ]	[e]	[ɛ]	[u]	[ʊ]	[o]	[ɔ]	[a]/[ɑ]
Peterson and Barney (1952)	136	135	NA[11]	130	141	137	NA	129	124
Hillenbrand et al. (1995)	138	135	129	127	143	133	129	121	123
Koffi (2016)	141	142	146	140	144	147	152	139	137

Table 5: Intrinsic Acoustic Correlate Values for Vowels

Ohala (1978:29) reports that "It has been noted over 50 years that, other things being equal, the average pitch of vowels shows a systematic correlation with height, that is, the higher the vowel, the higher the pitch." The vowels [i] and [u] are mentioned specifically as being associated with high pitch. Lehiste (1970:70) makes the same point. However, in Anyi, the F0 of the back vowel [o] is higher than that of [ʊ] and [u], and the F0 of [e] is also higher than [i] and [ɪ]. Koffi (2017) explains these exceptions by showing that [e] and [o] have risen higher than [ɪ] on the one hand, and [ʊ] on the other hand. The vowels [e] and [o] are on an upward shift, and this is causing a realignment in the Anyi vowel space.

6.4 The Intrinsic Value of Consonants and Pitch

It has been widely discussed in the literature that the phonetic feature [+stiff] of certain consonants causes the pitch of the vowels that immediately follow them to rise. The consonants that have this feature are [t, s, tʃ, ʃ, k]. They are all voiceless. Lehiste (1970:71) illustrates the effect of [+stiff] on pitch with the examples of /ti/ vs. /di/ and /tæ/ vs. /dæ/. She writes, "The differences were quite large; for example, the average peak of words beginning with the sequence /ti/ was 191 Hz, but of words beginning with /di/ it was 180 Hz; for /tæ/ and /dæ/, the average values were 175 Hz and 158 Hz." Anderson (1978:161) and Fromkin (1972:52) make statements in support of this view. However, Hombert (1978:81, 87) notes that "conflicting data are found from the same as well as other languages. They sometimes show no difference in F0 onset depending on the preceding consonant."

6.5 Intrinsic Segmental Values and Pitch Register in Anyi

Are the intrinsic values of the segments involved in /bʊ̀ká/ and /sìké/ responsible for the discrepancy between the results of the impressionistic and the instrumental analyses? Recall that those who have studied Anyi impressionistically claim that the pitch register of disyllabic verbs is CV̀CV́. However, the acoustic phonetic data has uncovered two different pitch registers. For /bʊ̀ká/, we have [bʊ̀kā], and for /sìké/, we have [sīkē]. The data set with which I'm working in this paper is extremely limited. Therefore, it does not support the view that vowel height or the consonantal feature [-voice, +stiff] has any impact on F0. If they did, the pitch of [bʊ̀ká] would not have lowered to [bʊ̀kā] because the presence of [k] would have caused [a] to rise, not lower. Similarly, if the intrinsic features of [sìké] played a role, one would have expected underlying pitch of [ì] to rise to mid. That is in fact what we have. The pitch of [ì] is 117 Hz, which corresponds to a mid pitch. However, it is inexplicable why the pitch of [é] lowered to mid. If the feature [+stiff] had any effect, the pitch should have stayed high or even climbed higher. But, that is not what we have. Instead, the pitch on the two vowels of [sīkē] is mid. All we can say at this preliminary stage in the research is that the pitch register of monosyllabic verbs is consistently high (CV́), whereas the register on disyllabic verbs vacillates between CV̀CV̄ and CV̄CV̄. Future research with more data may help explain why there is a discrepancy between the impressionistic claims and the instrumental analysis.

[11] The abbreviation NA indicates that [e] and [o] were not investigated.

7.0 Summary

The foregoing analysis has shown that the impressionistic statements about pitch levels need to be bolstered by instrumental acoustic phonetic data. This is what Quaireau (1978:170), Rivera-Castillo and Pickering (2004:273), Hogan (1998:76), and Downing (2008:62) tried to do. However, their findings leave much to be desired because they interpret F0 measurements impressionistically. The CBT-based analysis proposed in this paper introduces a new paradigm in which F0 measurements have corresponding pitch levels on the one-third octave template. This approach is based on the view that there are only five pitch registers in all human languages. The correlation between F0 measurements and pitch registers is reliable because the CBT template on which the new model is based is fully endorsed by the ANSI, the ISO, and the IEC. This new paradigm in tone analysis is authoritative and can, therefore, be used to study pitch registers and tone assimilation rules in all languages.

ABOUT THE AUTHOR

Ettien Koffi, Ph.D. in linguistics from Indiana University, teaches linguistics at Saint Cloud State University, MN. Author of many peer-reviewed articles on various topics in linguistics and of four books: *Language Society in Biblical Times* (1996), *Paradigm Shift in Language Planning and Policy: Game Theoretic Solutions* (2012), *Applied English Syntax* (2010, 2015), and the *New Testament in Anyi Morofu* (2017), a task which took over 25 years. Specializing in acoustic phonetics, dialect variation, and emergent orthographies, his current research centers on speech acoustics of L2 English (within the Speech Intelligibility Framework), Central Minnesota English, and Anyi. He can be reached at enkoffi@stcloudstate.edu.

References

Anderson, Stephen R. 1978. Tone Features. *Tone: A Linguistic Survey*, ed. by Victoria Fromkin, pp. 133-175. New York: Academic Press.

Békésy, Georg Von. 1947. Variations of Phase along the Basilar Membrane with Sinusoidal Vibrations. *The Journal of the Acoustical Society of America* 19 (3): 452-460.

Bolinger, Dwight L. 1958. A Theory of Pitch Accent in English. *Word* 14 (2-3): 109-149.

Bruel, P. V., J. Pope, and H.K. Zaveri. 1998. Acoustical Measurements and Instrumentation: Introduction. In *Handbook of Acoustics*, edited by Malcolm J. Crocker, pp. 1311-1316. New York: A Wiley-Interscience Publication, John Wiley and Sons, Inc..

Burmeister, Jonathan. 1983. L'Agni. *Atlas des Langues Kwa de Côte d'Ivoire*. Tome 1, ed. by G. Herault, pp. 155-172. Abidjan, Côte d'Ivoire: Institut de Linguistique Appliquée, Université d'Abidjan.

Creissels, Denis, and Nguessan Kouadio. 1977. *Description Phonologique et Grammaticale d'un Parler Baoule*. Abidjan, Côte d'Ivoire: Institut de Linguistique Appliquée, Université de Côte d'Ivoire.

Darwin C. J. and Carlyon R. P. 1995. Auditory Grouping. *Hearing: Handbook on Perception and Cognition*, ed. by Brian C. J. Moore, pp. 387-424. New York: Academic Press.

Downing, Laura J. 2008. Focus and Prominence in Chichewa, Chitumba, and Zulu. *ZAS Papers in Linguistics* 49:47-65.

Everest, Alton F. and Ken C. Pohlmann. 2015. *Master Handbook of Acoustics*. Sixth Edition. McGraw Hill Education: New York.

Fletcher, Harvey. 1940. Auditory Patterns. *Reviews of Modern Physics*, Volume 12, pp. 47-65.

Fromkin, Victoria A. 1985. Introduction, pp. 1-14. *Phonetic Linguistics: Essays in Honor of Peter Ladefoged*, ed. by Victoria A. Fromin. New York: Academic Press.

Fromkin, Victoria A. 1972. Tone Features and Tone Rules. *Studies in African Linguistics 3* (1): 47-76.

Fry, Dennis. B. 1979. *The Physics of Speech.* New York: Cambridge University Press.

Fry, Dennis. B. 1958. Experiments in the Perception of Stress. *Language and Speech* 1 (2): 126-152.

Fry, Dennis. B. 1955. Duration and Intensity as Physical Correlates of Linguistic Stress. *Journal of the Acoustical Society of America* 27 (4): 765-768.

Gandour, Jackson T. 1978. The Perception of Tone. *Tone: A Linguistic Survey*, ed. by Victoria Fromkin, pp. 41-76. New York: Academic Press.

Hansen, Colin H. 2001. Fundamentals of Acoustics. *Occupational Exposure to Noise: Evaluation, Prevention, and Control*. Ed. By Bernice Goelzer, Colin H. Hasen, and Gustav A. Sherndt. Dortmund, Germany: World Health Organization. https://extranet.who.int/iris/restricted/handle/10665/42429.

Hillenbrand, James, Laura A. Getty, Michael J. Clark, and Kimberlea Wheeler. 1995. Acoustic Characteristics of American English Vowels. *The Journal of the Acoustical Society of America 97.* 5. 3099-3111.

Hogan, John T. 1998. A Parallel Between Music and Speech Tonality and Tone. *Linguistic Atlantica* 20:73-84.

Hombert, Jean-Marie. 1978. Consonant Types, Vowel Quality, and Tone. *Tone: A Linguistic Survey*, ed. by Victoria Fromkin, pp. 338-365. New York: Academic Press.

Houtsma, A. J. M. 1995. Pitch Perception. *Hearing: Handbook on Perception and Cognition*, ed. by Brian C. J. Moore, pp. 267-295. New York: Academic Press.

Hyman, Larry M. 2010. How to Study a Tone Language, with Exemplification from Oku (Grassfields Bantu, Cameroon). *UC Berkeley Phonology Lab Annual Report*, pp. 179-209.

Grantham, Wesley D. 1995. Spatial Hearing and Related Phenomena. *Hearing: Handbook on Perception and Cognition*, ed. by Brian C. J. Moore, pp. 297-345. Academic Press: New York.

Kenstowicz, Michael. 1994. *Phonology in Generative Grammar*. Cambridge, MA: Blackwell.

Koffi, Ettien. 2017. The Acoustic Vowel Space of Anyi in Light of the Cardinal Vowel System and the Dispersion Focalization Theory. In Jason Kandybowicz, Travis Major, and Harold Torrence (eds.), Linguistics on the Prairie: Selected Papers from the 45th Annual Conference on African Linguistics. Berlin: Language Science Press.[12]

Koffi, Ettien. 2016. The Acoustic Correlates of [±ATR] Vowels: An Analysis by Reference Levels of Anyi Vowels. *Linguistic Portfolios* 5:115-134.

Koffi, Ettien. 2012. *Paradigm Shift in Language Planning and Policy: Game-Theoretic Solutions*. Boston, MA: De Gruyter Mouton.

Ladefoged, Peter. 2003. *Phonetic Data Analysis: An Introduction to Fieldwork and Instrumental Techniques*. Malden, MA: Blackwell Publishing.

Ladefoged, Pater and Ian Maddieson. 1996. *The Sounds of the World's Languages*. Malden, MA: Blackwell Publishers.

Lehiste, Lise. 1970. *Suprasegmentals.* Cambridge, MA: The MIT Press.

[12] Upcoming publication. Page numbers to be assigned.

Maddieson, Ian. 1978. Universals of Tone. *Universals of Human Language*, ed by Joseph H. Greenberg, Volume 2, pp. 338-365. Stanford University Press: Stanford, CA.

Miller, James D. 1989. Auditory-perceptual Interpretation of the Vowel. *Journal of the Acoustical Society of America* 85 : 2114-2134.

McWhorter, John. 2003. *The Power of Babel: A Natural History of Language*. New York: Perennial.

Moerel, Michell, Federica de Martino, and Elia Formisana. 2012. Processing of Natural Sounds in Human Auditory Cortex: Tonotopy, Spectral Tuning, and Relation to Voice Sensitivity. *Journal of Neuroscience* 32 (42):14205-14216.

Ohala, John. 1978. Production of Tone. *Tone: A Linguistic Survey*, ed. by Victoria Fromkin, pp.5-39. New York: Academic Press.

Palmer, Alan R. 1995. Neural Signal Processing. *Hearing: Handbook on Perception and Cognition*, ed. by Brian C. J. Moore, pp. 75-121. New York: Academic Press.

Peterson, Gordon E, and Harold L. Barney. 1952. Control Methods in a Study of the Vowels. *The Journal of the Acoustical Society of America 24.* 2. 176-84.

Pope, J. 1998. Analyzers. *Handbook of Acoustics*, ed. by Malcom J. Crocker, pp. 1341-1353. A Wiley-Interscience Publication: New York.

Ritsma, Roelof J. 1967. Frequencies Dominant in the Perception of Pitch of Complex Sounds. Journal of the *Acoustical Society of America* 42 (1): 191-198.

Quaireau, Andre. 1978. *Essai d'Interpretation des Faits Phonologiques de l'Agni*. Thèse de Doctorat 3ème Cycle: Universite de Nancy II, France.

Ritsma, Roelof J. 1967. Frequencies Dominant in the Perception of Pitch of Complex Sounds. *Journal of the Acoustical Society of America* 42 (1): 191-198.

Rivera-Castillo, Yolanda and Lucy Pickering. 2004. Phonetic Correlates of Stress and Tone in a Mixed System. *Journal of Pidgin and Creole Languages* 19:2, 261-284.

Ryan, Kevin. 2005. Grid-maker.praat. Available online at: http://www.linguistics.cla.du/faciliti/facilities/acoustic/praat.tml.

Scharf, Bertram (1961: 215). Complex Sounds and Critical Bands. *Psychological Bulletin*, Volume 50, 3:205-217. Retrieved from http://www.auditory.org/mhonarc/2012/pdfEmnQ4un9oz.pdf on April 16, 2016.

Stevens, Kenneth N. 2000. *Acoustic Phonetics*. Cambridge, MA: The MIT Press.

Stevens, Kenneth N. 1998. Models of Speech Production. In *Handbook of Acoustics*, edited by Malcolm J. Crocker, pp. 1231-1244. New York: A Wiley-Interscience Publication, John Wiley and Sons, Inc.

Traunmuller, Harmut and Anders Eriksson. n.d. The Frequency Range of the Voice of Fundamental in Speech of Male and Female Adults. Retrieved from http://www2.ling.su.se/staff/hartmut/f0_m&f.pdf on March 13, 2017.

The International Phonetic Association. 1999. *Handbook of the IPA: A Guide to the Use of the International Phonetic Alphabet*. Cambridge University Press: New York, NY.

Welmers, William E. 1973. *African Language Structures*. Los Angeles: University of California Press.

Zwicker, E. 1961. Subdivision of the Audible Frequency Range into Critical Bands (Frequenzgruppen). *The Journal of the Acoustical Society of America* 33 (2): 248.

Linguistic Portfolios–ISSN 2472-5102 –Volume 6, 2017 | 165

Appendix

Words	/dí/	/kɔ́/	/bʊ̀	ká/	/sì	ké/
Duration in ms	[i]	[ɔ]	[ʊ]	[a]	[i]	[e]
Speaker 1	76	77	66	73	42	71
Speaker 2	112	121	81	77	48	113
Speaker 3	132	90	55	97	78	124
Speaker 4	106	73	68	53	61	88
Duration Mean	**106**	**90**	**67**	**75**	**55**	**99**
St. Deviation	23	21	10	18	12	23

Words	/dí/	/kɔ́/	/bʊ̀	ká/	/sì	ké/
Intensity in dB	[i]	[ɔ]	[ʊ]	[a]	[i]	[e]
Speaker 1	62	63	59	62	59	61
Speaker 2	74	80	81	77	77	76
Speaker 3	78	72	80	78	78	77
Speaker 4	74	74	66	66	68	70
Intensity Mean	**72**	**72**	**71**	**70**	**70**	**71**
St. Deviation	6	7	10	7	8	7