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Measurement of "Tone" — A Technical Aspect

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Abstract. The purpose of this research work is to measure the Tone value. The recorded speech material consists of the extracted portion of a syllable **k** - (from *k ṛa*: 'horse') is used for measuring the momentum of the pitch in tone. A native speaker of Punjabi language from the Doab region (Punjab, India) has been selected for producing the word *k ṛa*: (the focus of this work is not on the sociolinguistic study of the data of the native speaker). On the basis of the simple graphical representation a formula has been applied for measuring the tone value of the language. This paper seeks to improve our competence regarding acoustic measurements of acoustic data through graphical representation.

1. Introduction

'Measurement' is a technique of calculating the physical properties. There are different ways like: scales, time clocks, etc. of measuring lengths (including widths) and time. With the help of modern techniques of measurement, we can even determine the age of a tree or the period of a fossil (by carbon dating etc.). For measuring anything one must adopt a **unit** which should be considered as a **standard** of measurement. The measurement is also of potential importance for the experimental study in the fields of phonetics and laboratory phonology. Different experimental studies on segmental and suprasegmental (or autosegmental) features have pointed to the important roles of different acoustic elements (like: duration, pitch, intensity etc.) in building the linguistic theories. Fant [6, 7], Ladefoged [19, 20, 21], Crystal [4], Lehiste [9], Halliday [17, 18], Ohala [14], Pierrehumbert [13], Gussenhoven [2], Cruttenden [1], Joshi [24], Ladd [5], Laver [12], Gargesh [22], Rogers [8] and Singh [3] have analyzed segmental and suprasegmental features, acoustically. However, the present study can be clubbed with the studies of Lehiste [9], Pierrehumbert [13], Ladd [5], Gussenhoven [2], and Cruttenden [1].

Lehiste's work on tone is based on the fundamental frequency. Lehiste ([9, p. 83]) says- "Contrastive function of fundamental frequency at word level is called tone". Lehiste's work cannot depict the movement of pitch. His work fails in

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demonstrating the high and low bitonal functions of a pitch. In the course of the hunt for defining tones or pitch levels, Pierrehumbert [13] and Ladd [5] proposed an account of suprasegmental features (tone and intonation) using H (high) and L (low) tones or pitch levels at the risk of ad-hoc solutions. Their solutions do not solve a significant acoustic problem i.e. the measurement of movement of the pitch of tonal elements.

The nuclear tones in British English were investigated by Gussenhoven [2]. He takes three (the rise L∗H, the fall H∗L and the fall-rise H∗LH) among the nuclear tones as the basic tones. Gussenhoven's claim that there are three basic tones (=nuclear tones) is unclear. He points out that there is a combination of nuclear tones which can make up to twelve nuclear tones. He further argues that even these twelve nuclear tone combinations cannot capture all the tones found (for details cf. [2, p. 232]). Such a discussion is so vague that one cannot reach any conclusion. Gussenhoven's [2] study lacks experimental phonetic evidences. There had been another significant investigation concerning pitch patterns, notably Cruttenden [1]. Cruttenden [1] introduces five types of pitch patterns in English (in Yes-No question type) without any quantitative (mathematical) evidence (cited in [12, p. 489]).

In short, the experimental findings of all the above mentioned studies are modeled much more on the traditional basis (i.e. H and L tones or rising and falling pitch patterns) of studying suprasegmental features. In general, several studies on tone have presented the distinction between High (H), Low (L) and various pitch patterns by using fundamental frequency as an acoustic parameter. But researchers have not provided the measurement of the momentum of pitch (in a tone) on a graph. All these studies do not calculate the pitch change on the basis of onset or offset of the pitch in a tone. The present work is offered as a research paper to develop our ability to measure tone. In this paper I build a unit of **tone** which is an essential feature of many languages of the World.

2. Tone Measurement: An overview

Tone is a significant feature of many languages of the World, as Fromkin ([25, p. 1]) says "the majority of the World's languages are tone languages". Although this paper does not provide any classification of tonal and non-tonal languages of the World. The nature of tone rules (whether these tone rules are similar to or different from other phonological rules) will not be discussed in this paper. This study provides the measurement of tone in a language.

Tone and the role of pitch for making a tone have been defined by many linguists. While describing tones Pike and Pike ([16, p. 324]) have rightly observed that the pitch gap between the tones has not yet been measured and the range of deviation for each of the tones must await instrumental analysis. As Gandour ([15, p. 41]) assumes that "the principle phonetic features of tone are found in the domain of pitch". He further states that "a tone language... is a language in which pitch is used to contrast individual lexical items or words".

Clark and Yallop ([1, p. 304]) described tone as a pitch pattern. In the present work, the main goal of measuring the tone is to calculate the pitch value of the syllable. The concept of calculating pitch values is definitely chosen with a view to attaining systematic explanations and not merely description. This study is based on the instrumental study and speech analysis software i.e. **Praat (4.0.5)** has been selected for analyzing the Punjabi language data of my own spoken form. I am the native speaker of Punjabi language. The data was rechecked by my parents. The present paper is an attempt to study the factors that may account for measuring the tone values.

Anderson ([23, p. 138]) limits the tone levels by assuming that pitch can vary continuously across a wide range of frequencies, depending on the conjunction of a number of factors. He says "much of this variation is not linguistically significant; features of individual voice range, for example, should presumably not be reflected in linguistic descriptions of tone". He further states that emotional and expressive factors, unrelated to any other linguistically determined aspect of an utterance, also play a prominent role in the domain of pitch, but again these factors should presumably be not taken in account for arriving at a purely linguistic representation of a tone.

It has been noticed that the native speakers can easily identify the tonal variations in real speech, but the measurement of tone and tonal variation has always been a great problem for the linguists or speech analysts or phoneticians. The focal point of this paper is to take pitch change as the main acoustic cue for measuring the tone. Pitch change is calculated on the basis of onset or offset of the pitch of the tone. For measuring the tone of a language, a pitch-time graph is used and on the basis of this **pitch-time** graph a formula has been constructed. A **pitch-time** graph from the picture prints of the pitch accented vowels **,** and one vowel with neutral pitch i.e. **ō**, are taken by using **Praat (4.0.5)** Picture windows. The pitch accented vowels (**,** , and **ō**) are the extracted portions of **k** (from *k ṛa*: 'leper'), **k** (from *k ṛa*: 'horse') and **kō** (from *kōṛa*: 'whip') syllables of Punjabi language.

3. **Tone Measurement: A Graphical Representation**

A linguistic data obtained through a research can be best understood by plotting graphs. Graphical representation is a useful tool for visualizing the plots of the data. Graphical representation can also describe the plots mathematically.

3.1. *Graphical Representation*

Graphical representation is a valuable tool to present the two-dimensional picture of wave motion. The traveling aspect of the wave can be illustrated drawing a chain of particle displacement, particle position curves at successive intervals of time. The curves can also be drawn for a small time interval. It can also be seen how the displacement changes in the time interval vary with particle position (for

details cf. [11, pp. 187–191]). In this study the change in pitch values in a given time has been taken into consideration.

Graphical study, here, presents the change in pitch values (from maximum to minimum) which can elucidate the systematic variation in tone with a detailed statistical analysis. The Figure 1, illustrates the graphical representation of tone measurement in a language. In this figure the falling tone of Punjabi has been selected for the graphical illustration of measurement.

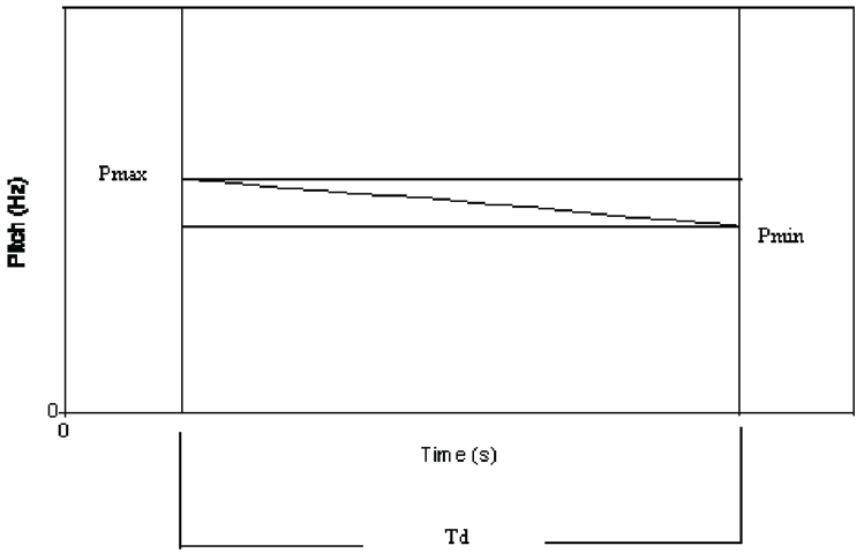

Figure 1. Graphical representation of tone measurement ([Pmin: minimum pitch value, Pmax: maximum pitch value, Td: time duration])

Figure 1 gives us the following valuable acoustic cues:

(i) *Pitch movement*: The movement in the pitch is due to the disturbances created in it. The disturbances generate the displacement of pitch from its one position to another. The pitch movement can be expressed in the form of maximum pitch value (**Pmax**) and minimum pitch value (**Pmin**).

(ii) *Time duration*: Total distance covered by the pitch in a given time, represented by **Td**.

Let us measure the tone in terms of pitch variation i.e. change in pitch from maximum point to minimum point. The tone measurement can be described using the formula:

$$\text{Tone} = \frac{\text{Change in pitch from maximum to minimum}}{\text{Time duration}} \text{ Hz/s} \tag{3.1}$$

or

$$\textbf{Tone} = \frac{\textbf{Pmax - Pmin}}{\textbf{Td}} \textbf{Hz/s}$$

The above formula can also be seen as a default rule that "**the change in pitch (Min → Max or Max → Min) per unit time is known as *tone***". Here, the variation in pitch is due to change in the direction of the motion of pitch with time. We can also say that if **P** is a general observation point on the graph, the positions of **Pmax** and **Pmin** interchange as per the pitch values.
If we look into all such changes, we shall find that there can be three kinds of pitch movements or tones in Punjabi language: Rising Tone, Falling Tone and Level Tone.

3.2. *Pitch movements in Punjabi language*

Pitch movement depends on a number of factors and these factors vary as per the acoustic environment. In the acoustic study of the features of pitch movement it is necessary and adequate to quantize the tone. This section provides the picture of graphical study of tone measurement by taking into consideration the three kinds of pitch movements or tones (Rising Tone, Falling Tone and Level Tone) in Punjabi language.

3.2.1. *Rising Tone.* When a pitch changes its position with the passage of time from its minimum value to its maximum value in other words when **Pitch increases with time** can be considered as a rising tone. In Figure 2, rising pitch accent is illustrated by red marking in the picture. Here, **k** is the essential syllable of **k ṛa**:.

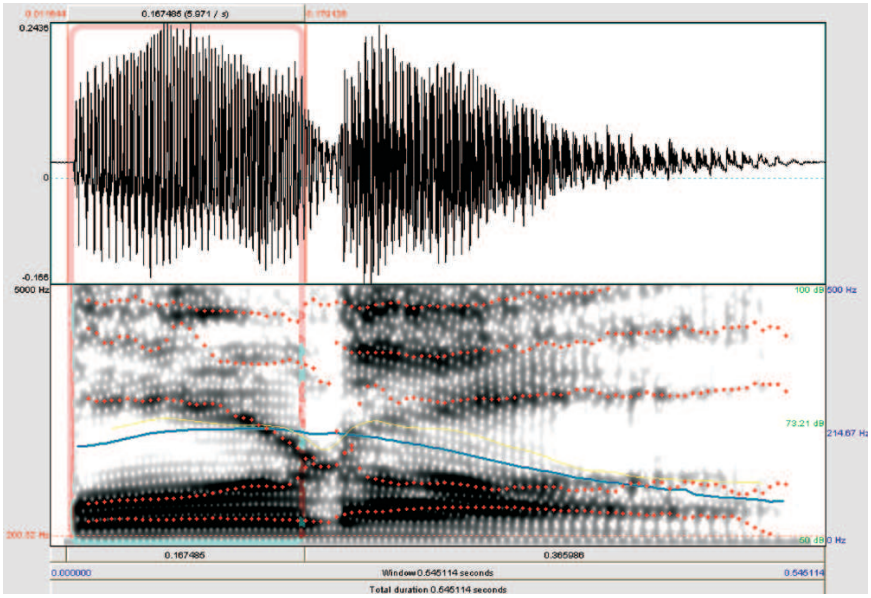

Figure 2. k ṛa: (laper)

Figure 2 illustrates the realization of pitch accented vowel of syllable **k** - (**k** - **is in the red colored box**) in the context of rising pitch (shown by blue line). This

vowel displays periodic wave and the formant structure of a high rounded vowel. Pitch accented vowel of **k** - syllable can be represented graphically as follows:

The graphical representation in Figure 3 shows that the pitch has moved from Pmin i.e. 198.75Hz to Pmax i.e. 220.78Hz in a time duration 0.08s (0.095561s-0.019611s). Let us use the formula to measure the Rising Tone.

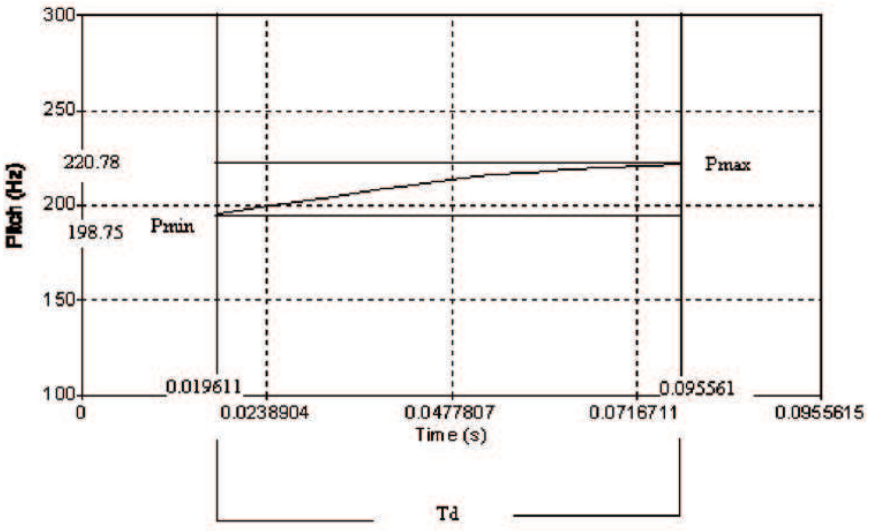

Figure 3. Graphical representation of rising tone measurement

3.2.1.1. *Use of the Formula for Calculating the Punjabi Rising Tone.* For calculating the Punjabi tone, numerical values have been taken from the graph in Figure 3:

$$\text{(3.2)} \quad \textbf{Rising Tone} = \frac{\mathbf{220.78 - 198.75}}{\mathbf{0.08}}\mathbf{Hz/s}$$

$$= \frac{\mathbf{22.03}}{\mathbf{0.08}}\mathbf{Hz/s}$$

$$= \mathbf{275.4Hz/s}$$

Where, 22.03Hz is the pitch difference between two pitch points of rising tone and rising tone occurs when the pitch difference is divided by the time duration (i.e. 0.08s). The calculated Rising Tone is 275.4Hz/s.

3.2.2. *Falling Tone.* When a pitch changes its position with the passage of time from its maximum value to its minimum value in other words when **Pitch decreases with time** can be considered as a falling tone. In several Punjabi speaking communities the falling tone effect is very strong in the running speech as it is quite observable in test words as well as in citation sentences. The falling tone needs to be inspected in the context of the essential acoustic information obtainable in Figure 4:

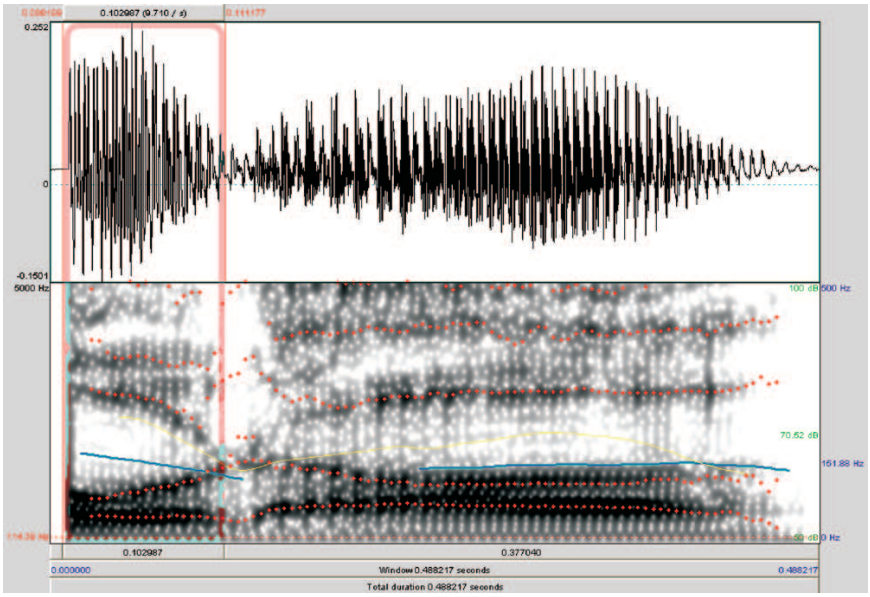

Figure 4. k ṛa: (horse)

Figure 4 illustrates the realization of pitch accented vowel of syllable **k** - (**k** - **is in the red colored box**) in the context of falling pitch (shown by blue line).

Acoustically extracted vowel of **k** - syllable can be measured graphically as in Figure 5:

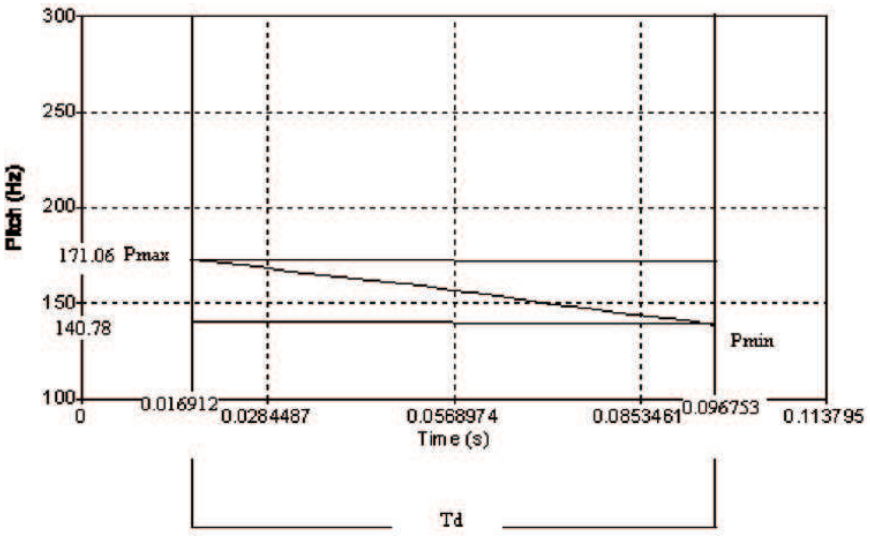

Figure 5. Graphical representation of falling tone measurement

The graph in Figure 5 indicates that the pitch has moved from Pmax i.e. 171.06Hz to Pmin i.e. 140.78Hz. in a time duration 0.08s (0.096753s-0.016912s). Now we use the formula to measure the Falling Tone.

3.2.2.1. *Use of the Formula for Calculating the Punjabi Falling Tone.* For calculating the Punjabi tone, numerical values are taken from the graph in Figure 5:

$$\text{(3.3)} \quad \textbf{Falling Tone} = \frac{\textbf{171.06 – 140.78}}{\textbf{0.08}}\textbf{Hz/s}$$

$$= \frac{\textbf{30.28}}{\textbf{0.08}}\textbf{Hz/s} = \textbf{378.5Hz/s}$$

Where, 30.28Hz is a significant difference between the two pitch points of falling tone. Falling tone occurs when the pitch difference is divided by the time duration (0.08s). The calculated Falling Tone is 378.5Hz/s.

3.2.3. *Level Tone.* Pitch is not necessarily moved with noticeable pitch values. When a pitch changes its position with the passage of time without acoustical significant change in the maximum value minimum value in other words when **there is No (or negligible) change with time** can be considered as a level tone. In Figure 6, level pitch accent is investigated.

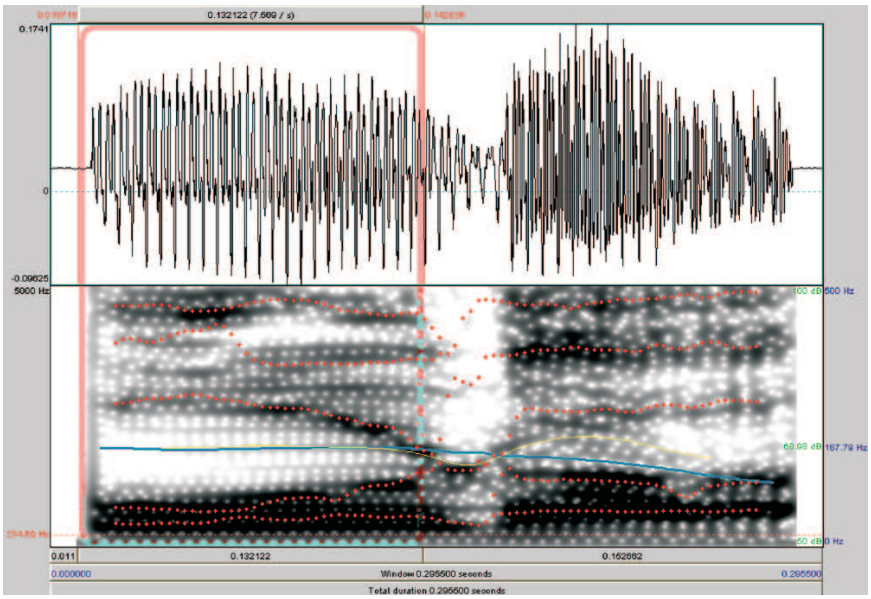

Figure 6. k ṛa: (whip)

Figure 6 shows the formant structure of a high rounded vowel (i.e. **ō** of syllable **kō- as shown in red box**). Here, the pitch (shown in blue line) does not show

an acoustical significant change. The graphical representation of **ō** is illustrated as follows:

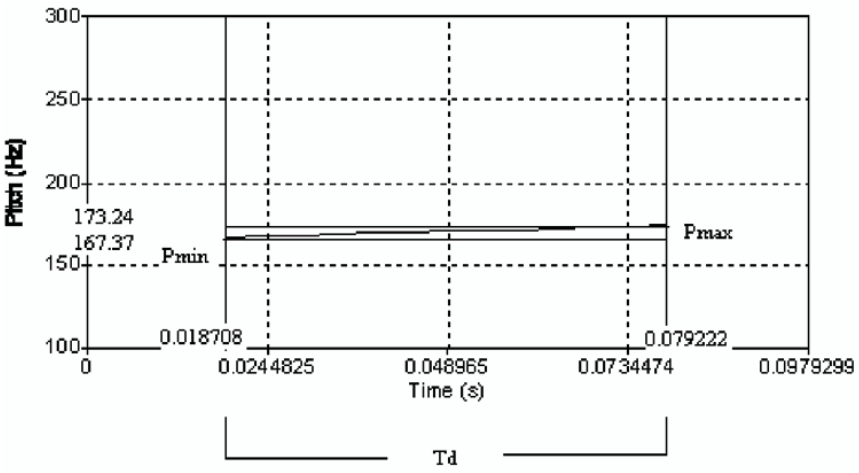

Figure 7. Graphical representation of level tone measurement

The graph in Figure 7 indicates that the pitch has moved from Pmax i.e. 173.35Hz to Pmin i.e. 167.46Hz (which is negligible or not the acoustically significant change) in a time duration 0.06s (0.079222s-0.018708s). Now we use the formula to measure the level Tone.

3.2.3.1. *Use of the Formula for Calculating the Punjabi Level Tone.* For calculating the Punjabi tone, numerical values are taken from the graph in Figure 5:

$$\begin{aligned} \textbf{Level Tone} &= \frac{\mathbf{173.24 - 167.37}}{\mathbf{0.06}}\mathbf{Hz/s} \\ &= \frac{\mathbf{5.87}}{\mathbf{0.06}}\mathbf{Hz/s} \\ &= \mathbf{97.8Hz/s} \end{aligned} \tag{3.4}$$

The calculation presented in (4) indicates that there is no significant difference between the maximum pitch point and minimum pitch point. The calculated Level Tone is 97.8Hz/s.

The above discussions give us an idea of the different kinds of pitch movements in the tones of Punjabi language. The measurements of Rising, Falling and Level Tones mentioned in the previous subsections provide acoustic description of the variation in the pitch movements. Pitch shows a remarkable deviation in the case of Pmin and Pmax, (as shown in Figure 8) and it also reveals a significant main effect of tonal variation in the language as illustrated in the form a line diagram in Figure 9. The line diagram in Figure 8 presents the pitch deviation in Punjabi

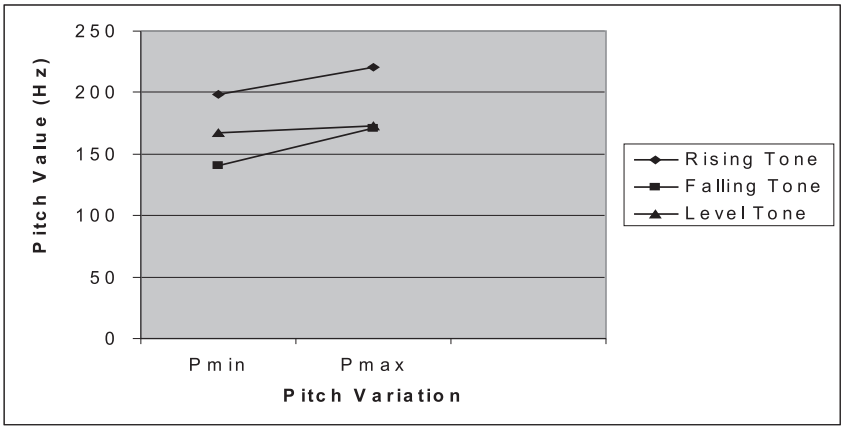

Figure 8. Line diagram of Pitch deviation

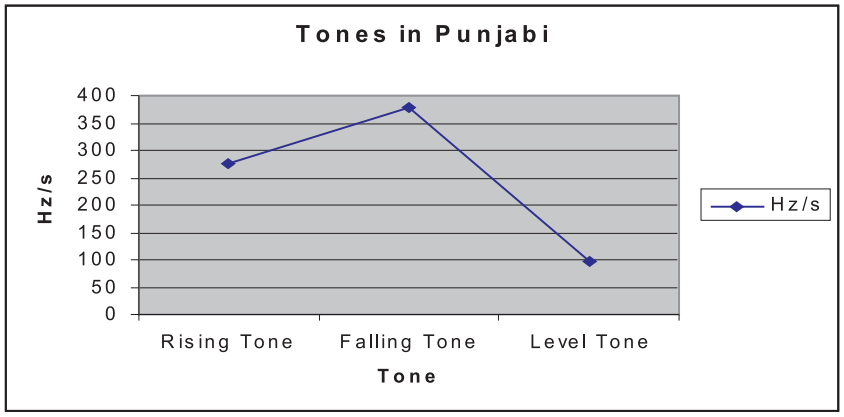

Figure 9. Line diagram of Tone Measurement

Tones. The crucial point is the numerical difference among the three tones (Rising, Falling and Level) that provides evidence for a pitch variation impact in Punjabi.

The difference in Pmax and Pmin values of pitch accented vowels , , and **ō** is maximal in the case of i.e. 30.28Hz. This difference is reduced to 22.03Hz. in the case of and 5.87Hz. in **ō** (which is negligible). The time durations in the graphical study are same in the Pitch-time graph of and but the time duration is decreased by 0.02s in Pitch-time graph of **ō**. Above all these results, the most interesting and the most significant results are found in the case of application of formula for measuring the tones. The falling tone has the highest tone value i.e. 378.5Hz/s. and the level tone shows the lowest or almost negligible i.e. 97.8Hz/s. These results are represented in Figure 9. The line diagram in Figure 9 is very informative the measures analysis of pitch movements in a language.

It can be seen from the above calculations and diagrams that the variation in the pitch of the **pitch-time** graph represents the tone value in time duration.

Note. This work deals with the graphical representation of tone system in any tonal language of the world.

4. Conclusion

It appears from the quantitative results presented in this study that falling tone in Punjabi uses a wider range of pitch movement. It seems that a native speaker of Punjabi can produce falling tone more readily than the rising and level tones. On the basis of experimental analysis (as discussed in the previous sections and subsections) we can infer that it is the pitch movement that has greater experimental and perceptual salience if we measure the tone of a language.

Finally, I would like to say that this work has presented a graphical representation for measuring the tone. The present investigation has not only examined the use of graphical method in the acoustic analysis of tone but also demonstrated the technical applications of Physics and Mathematics in the field of Linguistics.

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