Experimental Study on Monosyllabic Tones in the Dunhuang Hedong Dialect

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Abstract. This article uses experimental phonetics to study the tones of the Dunhuang Hedong dialect. It analyzes the tone types of the Dunhuang Hedong dialect and discusses the fundamental frequency changes and pitch range of each tone type. The experimental results show that the Dunhuang Hedong dialect has four tone types: the dark level tone (213), the light level tone (24), the rising tone (51), and the departing tone (44). The main purpose of this article is to provide an objective description of the actual situation of monosyllabic tones in the Dunhuang Hedong dialect through detailed and accurate data analysis. It summarizes the tone classes and values of monosyllabic tones and provides a certain reference value for future in-depth studies of the Dunhuang dialect.

Keywords: Dunhuang Hedong Dialect, Monosyllabic Tones, Experimental Phonetics, Tone Studies.

1. Introduction

Dunhuang is located at the westernmost end of the Hexi Corridor, at the junction of Gansu, Qinghai, and Xinjiang in China. It is situated between 92°42′E to 95°30′E longitude and 39°38′N to 41°34′N latitude. Within its territory, the Sanwei Mountains lie to the east, the Mingsha Mountain to the south, the desert connects with the Taklamakan Desert to the west, and the Gobi Desert connects with the Tianshan Mountain range to the north. The total area of the city is 26,700 square kilometers, of which the oasis area is only 1,991 square kilometers, accounting for just 7.18% of the total area, and is surrounded by the Gobi Desert, earning it the nickname "Gebi Oasis" [1,2]. Dunhuang has a total population of 200,000 people, with residents from various ethnic groups such as Han, Hui, Tibetan, Uighur, Mongolian, Kazakh, Tu, Miao, Man, and Yugu, with the Han ethnic group making up the majority.

Dunhuang is divided into two dialects by the Dang River, which runs north to south: Hedong dialect (East River dialect) and Hexi dialect (West River dialect). Hedong dialect is used in the towns east of the Dang River and belongs to the Zhongyuan Mandarin; Hexi dialect is distributed in the towns of Suzhou and Huangqu to the west of the Dang River, as well as Bazichang Village, and belongs to the Lanyin Mandarin[3]. Hedong dialect has distinct characteristics of Zhongyuan Mandarin Qinling language, while Hexihua has the features of Lanyin Mandarin Hexi dialect. The formation of Hedong dialect is mainly related to Dunhuang's history of immigration and the residential characteristics of immigrants. Due to Dunhuang's geographical location and transportation, the Hedong dialect has not undergone significant changes since the large-scale immigration in the third year of the Yongzheng period and has considerable differences from the language used in the "Hexi Corridor" to the east of Dunhuang (which belongs to Lanyin Mandarin Hexi dialect), making it a dialect island in the northwest dialects.

This article selects Hedong dialect as the research object. At present, most studies on Hedong dialect rely on traditional linguistics' auditory transcription methods, with few using experimental phonetic methods for precise analysis and research of initials, finals, and tones in the Hedong dialect. This article employs experimental phonetics to extract parameters such as fundamental frequency and duration for quantitative research of single-word tones in the Hedong dialect, objectively studying the specific performance of the tone system in the Hedong dialect.

2. Experimental Design

2.1 Pronunciation Word List

The main task of this experiment is to use experimental phonetics methods to comprehensively and meticulously analyze and describe the tones of Dunhuang Hedong dialect. According to the "Chinese Language Resources Survey Handbook - Chinese Dialects"[4] published by the Chinese Language and Script Work Committee, this article will determine the pronunciation word list for the experiment (see Table 1). The word list subdivides the four tones of level, rising, departing, and entering intso four categories: fully aspirated, lightly aspirated, lightly voiced, and fully voiced, each category selecting 4-5 representative characters for recording and research.

Table 1. Pronunciation Word List

Ancient tone	Ancient sound	Example characters	Ancient tone	Ancient sound	Example characters
Level	Fully aspirated	该,灯,东,风	Departing	Fully spirated	怪,四,半,冻
	Lightly aspirated	开,天,春,通		Lightly aspirated	去,快,寸,痛
	Lightly voiced	牛,油,门,龙		Lightly voiced	路,卖,乱,硬
	Fully voiced	皮,糖,铜,红		Fully voiced	树,地,饭,洞
Rising	Fully aspirated	古,鬼,九,懂	Entering	Fully aspirated	搭,急,节,百,谷
	Lightly aspirated	苦,讨,草,统		Lightly aspirated	塔,切,刻,拍,哭
	Lightly voiced	五,买,老,有		Lightly voiced	叶,月,麦,六
	Fully voiced	罪,后,近,动		Fully voiced	盒,罚,白,毒

2.2 Experimental Phonetic Recording

The pronunciation collaborator selected for this article is a young man who speaks the Dunhuang Hedong dialect. He was born in Shazhou Town, Dunhuang, and studied outside his hometown during college. After graduating from university, he has been working in Dunhuang. He can speak both the Dunhuang Hedong dialect and Mandarin. His parents and wife are also locals of Dunhuang, and they mainly communicate in the Dunhuang Hedong dialect in their daily lives.

The recording equipment used in this study includes a lapel microphone, a mixing console, an external sound card, a laptop, etc. The recording software used is Adobe Audition 3.0, which was used to record, segment, name, and store the pronunciation word list. The recordings were made in mono with a sampling frequency of 22050 Hz and a sampling accuracy of 16 bits, and the audio was saved in *.wav format. The Praat (speech analysis software) was used for speech annotation and parameter extraction, and Microsoft Excel 2010 was used to process the data and create various charts. A normalization script program was used to normalize the extracted parameters to remove individual characteristics and reduce pronunciation style differences during recording, in order to obtain speech information that is linguistically meaningful.

All the experimental data for this experiment were recorded in the recording studio of the Phonetics Laboratory in Northwest Minzu University. The pronunciation collaborator read the word list in a natural tone, and the recordings were saved as *.wav audio files.

2.3 Speech annotation

Before annotating speech, it is necessary to determine the components and targets of tones. In this study, we mainly refer to the two concepts clearly defined by Zhu Xiaonong in "The Phonetics"[5] - the components and targets of tones. Tones are composed of three parts: the tone head, the tone body, and the tone tail. The tone head refers to the first 10% to 20% of the pitch range affected by factors such as the consonant initial and the initial state. The tone tail refers to the last 10% to 20% of the pitch range affected by factors such as pitch decay and non-phonemic glottal stop endings. The tone body refers to the part of the pitch range that remains after removing the tone head and the tone tail.

The tone target refers to the parts of the tone that are more important for tone recognition. Its determination is based on statistical analysis of acoustic data, i.e., the acoustic data variance at that point is relatively small. In general, the peak of a tone is one of the tone targets, which can be explained from the aspects of tone contour and the three components of tone (see Table 2).

Table 2. Targets of tones

Tone contour	Tone target	Inflection point
Level tone	From tone head to tone tail	——
Rising tone	Tone tail (peak)	At the 20% duration point
Concave tone	Lowest inflection point (in tone body) or highest endpoint (in tone tail)	At the 20% duration point
Falling tone	Starting point (in the first 5% to 20% of the syllable, around the peak on junction of tone head and tone body)	——
Convex tone	Tone body (peak)	——

After determining the components and targets of tones, the duration of the tone needs to be measured. The duration of a tone is the duration of the rhyme body, which refers to the duration of the vowel and the rhyme tail, excluding the rhyme head. The starting point of a tone is calculated from the starting point of the vowel on a wideband spectrogram or from the second glottal pulse of the vowel on a waveform. The ending point of a tone is standardized as the point where the second formant of the vowel becomes unclear on a wideband spectrogram or where the amplitude significantly drops on a waveform. These are general standards for determining the starting and ending points of a tone, but consistency in measurement is crucial.

The Praat is used for speech annotation. A TextGrid file is generated based on the sound file, and annotation is performed on the TextGrid file. Tone annotation is performed on the Pinyin layer and the Shengyun layer based on the pitch curve, waveform, and auditory perception in the three-dimensional spectrogram. The first layer is the Pinyin layer, which marks the starting and ending points of the corresponding Chinese characters and syllables. The starting point is where the sound signal appears, and the ending point is where the second formant ends. The second layer is the syllable layer, which marks the starting and ending points of the rhyme of the syllable. The starting point is the second glottal pulse of the vowel on the spectrogram. To ensure the accuracy of the data, all speech annotations in this study are manually annotated. The following figure (Figure 1) is an example of tone annotation for the Dunhuang Hedong dialect. The annotated word is "该[kɛ]".

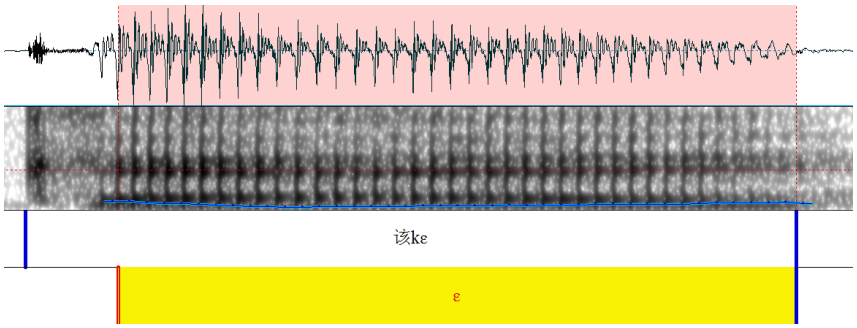

Figure 1. Example of Tone Annotation for Individual Words in the Hedong Dialect

2.4 Data Processing

(1) Data Extraction: The extraction of speech data was performed using Praat script programs, which were modified based on the scripts developed by Professor Wang Ting at Tongji University to meet the specific research objectives of this experiment (part of the source code is shown in Figure 2). The program was mainly used to extract parameters such as fundamental frequency and duration

of the language. To ensure the coherence of the data and the smoothness of the plotted lines, 30 fundamental frequency values were extracted for each syllable tone.

```
### Calculate Duration
            if interval_label$ != pause$ and interval_label$ != ""
                start = Get starting point... tier 'b'
                end = Get end point... tier 'b'
                duration = (end - start) * 1000

### Calculate f0
                select Pitch 'string$'
                maxpitch = Get maximum...  start end Hertz Parabolic
                maxTime = Get time of maximum...  start end Hertz Parabolic
                minpitch = Get minimum...  start end Hertz Parabolic
                minTime = Get time of minimum...  start end Hertz Parabolic
                meanpitch = Get mean... start end Hertz

### Measure pitch at 30 equidistant points per interval
                durationInSec = duration/1000
                oneNinth = durationInSec/29
                for t from 0 to 29
                    timef0Point = start+t*oneNinth
                    select Pitch 'string$'
                    x = t+1
                    f0Point'x' = Get value at time... timef0Point Hertz Linear
                    timeF0Point'x' = timef0Point
                endfor
```

Figure 2. Partial Script Program for Fundamental Frequency Extraction

(2) Data Preprocessing: In this experiment, Microsoft Excel 2010 was used to preprocess the extracted speech data. First, the fundamental frequency data of each syllable tone was imported into Excel according to the tone class. The mean value of the fundamental frequency sampling points of each example word under each tone class was taken to obtain the average fundamental frequency of each point under that tone class. Then, the fundamental frequency values were converted into pentatonic values, and T-value curve graphs were made for each corresponding tone class. During the analysis of the experimental results, if it was found that the experimental data for a particular sound pronounced by a speaker deviated significantly from the average data, the corresponding data would be removed.

(3) Normalization: The most convenient and effective way to describe tones is the pentatonic system. It was proposed by Zhao Yuanren in 1980 in "A Set of Alphabets for Standardizing Tones"[6]. The pentatonic system can indicate the tone class and the high and low changes of the tone value. It is an intuitive, easy-to-use symbol widely used in the recording and description of tonality in Chinese dialects and Sino-Tibetan languages, and has played a very important role[7].

The traditional method of tone marking involves investigators using their own experience of listening and remembering sounds, combining the speaker's pitch and determining the range of pitch, and then judging the rise and fall of the tone values and marking them as pentatonic values. This marking method is not a problem for determining the tone type and pitch of the tone, but the determination of the tone value mainly relies on human ears, that is, subjective perception, and lacks a certain degree of accuracy. Wang Shiyuan believed that pentatonic values are a relatively vague description of the actual pitch obtained indirectly through human ears[8]. Since the judgment of sound pitch by human ears does not have a completely linear correspondence with the results obtained from acoustic experiments[9], and even the same person will not produce exactly the same sound in the same environment, using Praat to extract fundamental frequency data does not have direct linguistic significance. In order to eliminate the inter-personal random differences in the recording process, reduce the differences in pronunciation styles of different speakers, extract constant parameters, filter out personal characteristics, and obtain information with linguistic significance, normalization of the fundamental frequency is necessary [10].

The fundamental frequency normalization in this study used the T-value method proposed by Shi Feng[7]. The selected example words were quantitatively analyzed to obtain tone class, tone type, and tone value for each syllable in the Hedong dialect. The T calculation formula is: $T = [(lgF0 - lgmin)/(lgmax - lgmin)] * 5$. where F0 is the average fundamental frequency value of the observation point, the min is the lower limit of the pitch range, the max is the upper limit of the

pitch range, and T is the normalized result. When the pitch is the lowest and highest, T is 0 and 5, respectively.

(4) Pentatonic Value Conversion: The T was converted into a pentatonic value using the "boundary" strategy proposed by Professor Liu Lili in "Dialect Experiments on Fundamental Frequency Normalization and Tone System Standardization"[11]. Based on the perception of fundamental frequency, each degree has a floating range of ±0.1 on the boundary. The specific correspondence between the T and the pentatonic value is as follows: the T between 0 and 1.1 correspond to pentatonic value 1; the T between 0.9 and 2.1 correspond to pentatonic value 2; the T between 1.9 and 3.1 correspond to pentatonic value 3; the T between 2.9 and 4.1 correspond to pentatonic value 4; the T between 3.9 and 5 correspond to pentatonic value 5.

3. Experimental Results and Analysis

3.1 Fundamental Frequency Range

The fundamental frequency data extracted from the speech in this study was uniformly processed. The starting average value, middle average value, ending average value, maximum value, and minimum value of the fundamental frequency for each group of ancient tone classes were calculated and compiled into a table for comparison and analysis. From this, the pitch range and fundamental frequency trend of each tone in the Hedong dialect were determined. The following are the fundamental frequency parameter tables for the level, rising, departing, and entering tone classes in Hedong dialect (see Table 3).

Table 3. The fundamental frequency parameter of level tone in Hedong dialect

Fundamental Frequency	Level Tone			
	Fully Aspirated	Lightly Aspirated	Lightly Voiced	Fully Voiced
Starting Average (Hz)	105.29	108.83	103.70	101.16
Middle Average (Hz)	96.04	99.00	111.61	113.02
Ending Average (Hz)	113.16	114.71	132.32	131.72
Maximum (Hz)	124.33	118.15	138.30	144.49
Minimum (Hz)	88.71	92.54	91.06	93.17

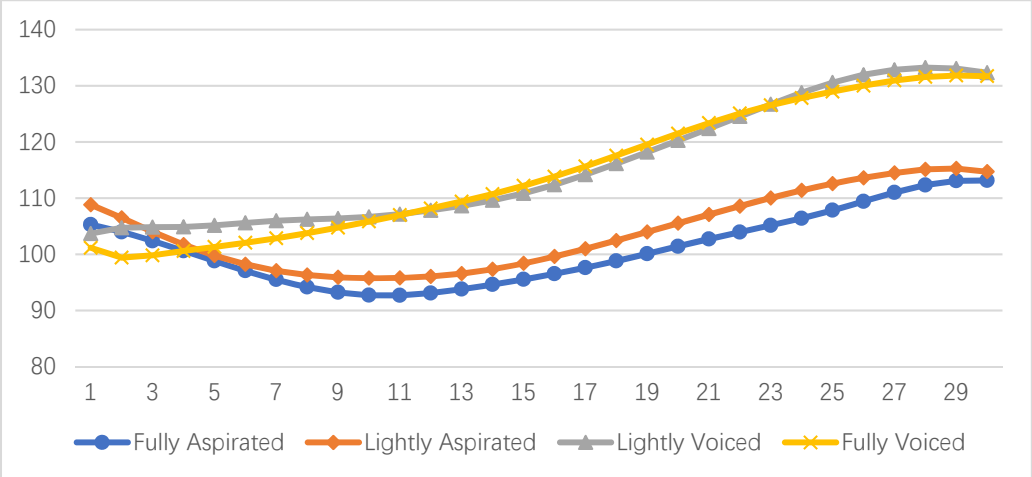

Figure 3. The fundamental frequency Curve of level tone in Hedong dialect

According to the rule of the development and evolution of Chinese tones, "the level tone dividing between the dark and light", it is known that the ancient level tone evolved into two tone classes: the dark level tone and the light level tone. Among them, the ancient aspirated initials (including fully aspirated and lightly aspirated) evolved into the dark level tone, while the ancient voiced initials

(including fully voiced and lightly voiced) evolved into the light level tone. The level tone in the Hedong dialect of Dunhuang also follows this pattern. As shown in Figure 3, the ancient level tone in the Hedong dialect has differentiated into two tones. The maximum value of the dark level tone is 124.33Hz, the minimum value is 88.71 Hz, and the pitch range is 35.62Hz. The maximum value of the light level tone is 144.49Hz, the minimum value is 91.06Hz, and the pitch range is 53.43Hz. The pitch range of the light level tone is larger than that of the dark level tone. Based on the starting average value, middle average value, and ending average value of the fundamental frequency, the tone type of the dark level tone in the Hedong dialect is a falling-rising tone, while the tone type of the dark level tone is a rising tone.

Table 4. The fundamental frequency parameter of rising tone in Hedong dialect

Fundamental Frequency	Rising Tone			
	Fully Aspirated	**Lightly Aspirated**	**Lightly Voiced**	**Fully Voiced**
Starting Average (Hz)	164.57	161.44	150.67	130.09
Middle Average (Hz)	123.66	116.00	121.21	137.07
Ending Average (Hz)	85.50	84.08	70.47	132.30
Maximum (Hz)	187.15	170.88	154.82	144.82
Minimum (Hz)	83.27	79.72	82.29	123.49

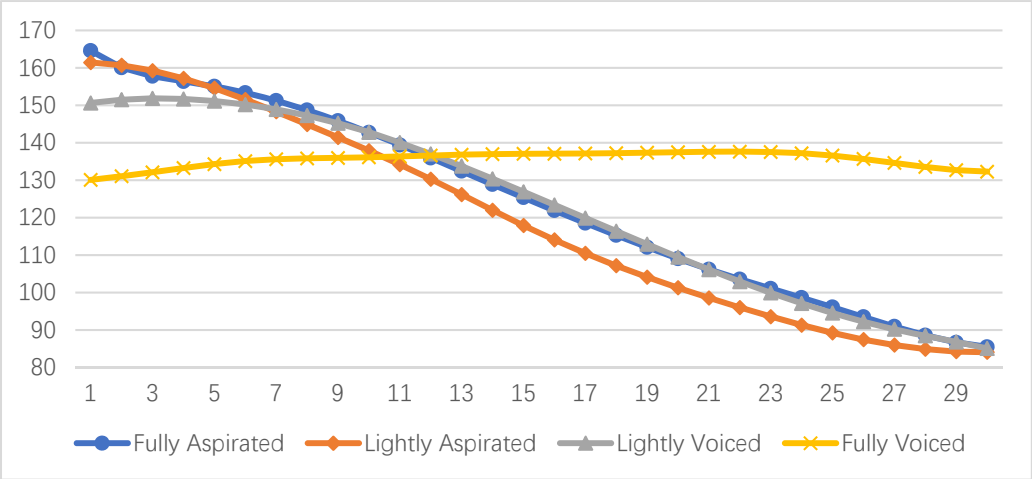

Figure 4. The fundamental frequency Curve of rising tone in Hedong dialect

The starting average value, middle average value, and ending average value of the fundamental frequency for the three groups of fully aspirated, lightly aspirated, and lightly voiced initials in the rising tone of the Hedong dialect are relatively close, and the fundamental frequency trend is consistent. The tone type is a falling tone, with a maximum fundamental frequency value of 187.15Hz, a minimum value of 79.72Hz, and a pitch range of 107.43Hz (see Table 4 for details). The maximum and minimum values and the fundamental frequency trend of the fully voiced rising tone are significantly different from the previous three, and the difference in the fundamental frequency between the starting average value, middle average value, and ending average value is not significant, with a gentle trend and a flat tone type. As shown in Figure 4, the ancient rising tone has differentiated into two tones. The rising tone of the ancient aspirated initials and the lightly voiced initials is now a falling tone, while the rising tone of the ancient voiced initials is now a level tone.

Table 5. The fundamental frequency parameter of departing tone in Hedong dialect

Fundamental Frequency	Departing Tone			
	Fully Aspirated	Lightly Aspirated	Lightly Voiced	Fully Voiced
Starting Average (Hz)	132.25	139.82	124.88	135.00
Middle Average (Hz)	132.49	139.62	129.12	132.24
Ending Average (Hz)	131.25	135.78	127.24	131.01
Maximum (Hz)	142.77	155.06	137.31	147.92
Minimum (Hz)	120.24	126.08	117.72	123.08

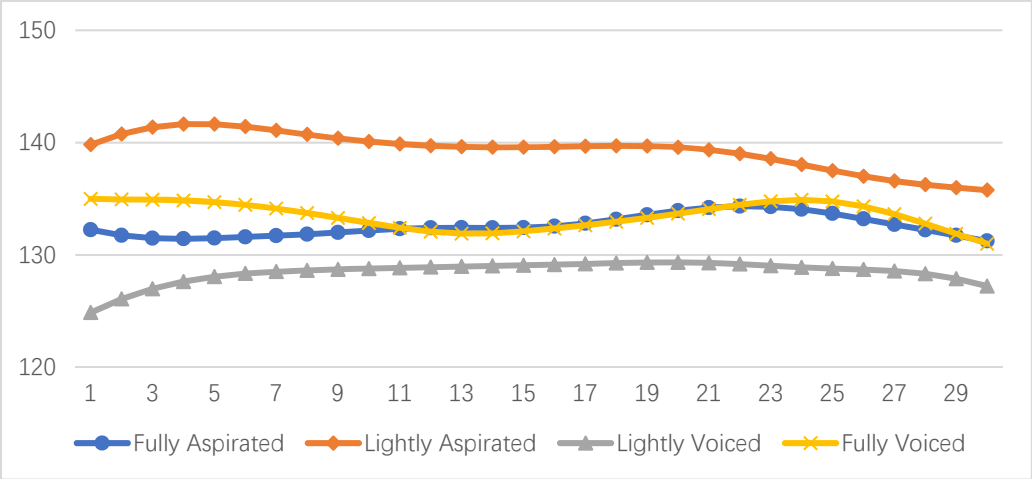

Figure 5. The fundamental frequency Curve of departing tone in Hedong dialect

As shown in Table 5, the fundamental frequency changes of the departing tone in the Hedong dialect are relatively small. The pitch ranges for fully aspirated, lightly aspirated, lightly voiced and fully voiced initials are 22.53Hz, 28.98Hz, 19.59Hz, and 24.84Hz, respectively. The pitch range is relatively small, and the starting average value, middle average value, and ending average value of the fundamental frequency are relatively close. The fundamental frequency trend is gentle, and the tone type is a level tone. In addition, the fundamental frequency range and pitch contour of the fully voiced rising tone in the Hedong dialect are relatively consistent with those of the departing tone, so the fully voiced rising tone can be merged into the departing tone. Although the fundamental frequency curves of each initial consonant in Figure 5 are uneven, the overall trend of the fundamental frequency is basically consistent, and the tone type is a level tone.

Table 6. The fundamental frequency parameter of entering tone in Hedong dialect

Fundamental Frequency	Entering Tone			
	Fully Aspirated	Lightly Aspirated	Lightly Voiced	Fully Voiced
Starting Average (Hz)	107.79	106.12	107.57	97.01
Middle Average (Hz)	96.44	93.74	103.77	105.66
Ending Average (Hz)	113.13	109.90	115.62	122.31
Maximum (Hz)	121.56	114.98	121.57	135.93
Minimum (Hz)	87.84	88.76	97.23	90.54

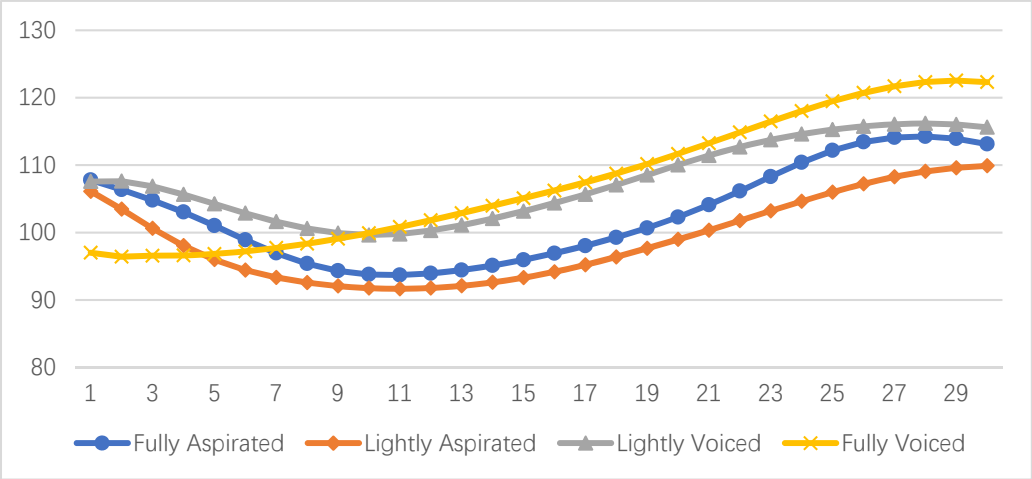

Figure 6. The fundamental frequency Curve of entering tone in Hedong dialect

In some dialects, the entering tone has disappeared. In phonetics, the specific situation of the "the entering tone is categorized into three tones" is that entering tone characters with fully voiced initials are categorized as light level tone, those with lightly voiced initials are categorized as departing tone, and those with fully aspirated initials are categorized as dark level tone, light level tone, or rising tone. By analyzing Table 6, the entering tone categorization in the Hedong dialect of Dunhuang can be summarized. The starting average value, middle average value, and ending average value of the fundamental frequency for entering tone characters with aspirated initials and lightly voiced initials in the Hedong dialect are generally consistent, with a falling-rising contour and a maximum fundamental frequency value of 121.57Hz, a minimum value of 88.76Hz, and a pitch range of 32.81Hz between 88.76Hz and 121.57Hz. The pitch range is relatively small. At the same time, the fundamental frequency values and contour trends of entering tone characters with aspirated initials and lightly voiced initials in the Hedong dialect are generally consistent with those of the level tone with aspirated initials, so they can be considered as a single tone type with a falling-rising contour.

The fully voiced rising tone has an upward tone contour from the starting average value, middle average value, and ending average value, with a maximum fundamental frequency value of 135.93 Hz, a minimum value of 90.54Hz, and a pitch range of 45.39Hz, which is relatively small. The fundamental frequency values and contour trends of entering tone characters with fully voiced initials in the Hedong dialect are generally consistent with those of the level tone with voiced initials, so they can be considered as a single tone type with a rising contour. Although the fundamental frequency values for entering tone characters with fully voiced initials are not significantly different from those with aspirated initials and lightly voiced initials in Figure 6, the contour trends of the fundamental frequency are not consistent. The entering tone characters with fully voiced initials have a rising contour, while those with aspirated initials and lightly voiced initials have a falling-rising contour.

In summary, the Dunhuang Hedong dialect in ancient times had four tones: level, rising, departing, and entering. However, significant changes have occurred in modern times. The level tone has differentiated into the dark level tone and the light level tone. The ancient aspirated initials in the level tone have evolved into the dark level tone with a falling-rising contour, while the ancient voiced initials in the level tone have evolved into the light level tone with a rising contour. The rising tone has differentiated, with fully aspirated, lightly aspirated, and lightly voiced initials in the rising tone still being a rising tone with a falling contour, while the fully voiced rising tone has merged with the departing tone and become a level tone. The departing tone has not differentiated during the evolution and is now a level tone. The entering tone has differentiated into two tone types, with entering tone characters with aspirated initials and lightly voiced initials now being a falling-rising contour, while those with fully voiced initials are now a rising contour.

3.2 Five Degree Values Analysis

The F0 fundamental frequency data collected in this experiment was normalized using a five-tone T-value normalization process, and a T-value contour graph of the Dunhuang Hedong dialect was created. Figure 7 shows the T-value contour graph of single syllable tones in the Hedong dialect. By analyzing the T-values and combining them with auditory perception, it can be determined that in the historical evolution of the ancient level tone in the Hedong dialect of Dunhuang, it has differentiated into the yin and yang level tones based on clear and voiced initials, with T-values of 213 and 24, respectively. The ancient aspirated initials and lightly voiced initials in the rising tone still read as rising tone with a T-value of 51, while the fully voiced initials in the rising tone have differentiated and merged with the departing tone into one tone category with a T-value of 44. The entering tone has differentiated into two tone types, with entering tone characters with aspirated initials and lightly voiced initials merged into the dark level tone with a T-value of 213, and those with fully voiced initials merged into the light level tone with a T-value of 24.

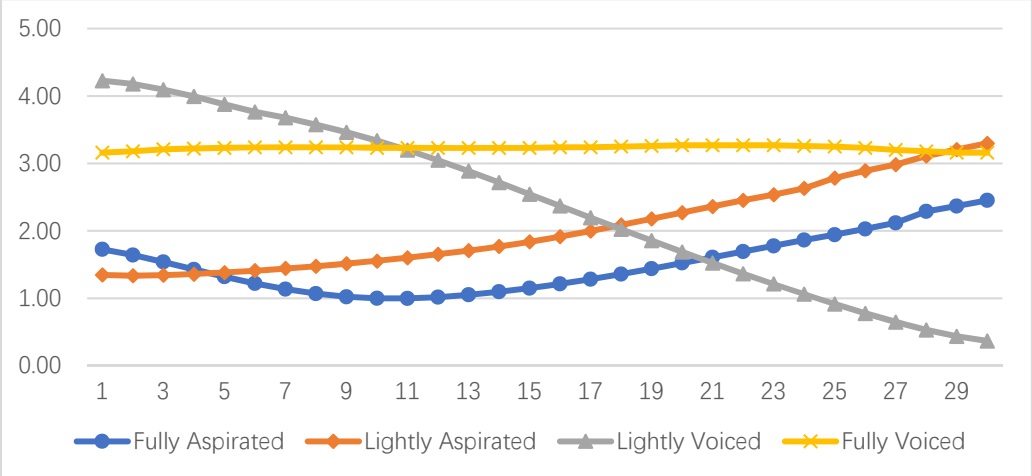

Figure 7. T-value contour graph of single syllable tones in the Hedong dialect

4. Conclusion

This article summarizes the development and evolution of tones in the Dunhuang Hedong dialect from Middle Chinese to the present through various methods, including field surveys, data analysis, and auditory perception tests. The tone categories and tone values of monosyllabic tones in the Dunhuang Hedong dialect are presented in Table 7. Overall, there are four tone categories in the Dunhuang Hedong dialect: the dark level tone has a falling-rising contour with a tone value of 213, the light level tone has a rising contour with a tone value of 24, the rising tone has a falling contour with a tone value of 51, and the departing tone has a level contour with a tone value of 44.

Table 7. The monosyllabic tones in the Dunhuang Hedong dialect

	Level Tone		**Rising Tone**		**Departing Tone**	**Entering Tone**	
	Aspirated	**Voiced**	**Aspirated, Lightly voiced**	**Fully voiced**	**Aspirated, voiced**	**Aspirated, Lightly voiced**	**Fully voiced**
Tone Category	the dark level tone	the light level tone	the rising tone		the departing tone	the dark level tone	the light level tone
Tone Value	213	24	51		44	213	24

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