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Formant Analysis of Single Vowels in Mandarin Spoken by Chinese Female Speakers

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ABSTRACT

This study aimed to investigate the formant measurement of single vowel sounds in the Mandarin spoken by Chinese female speakers. This study employed the audio method. The data were collected from five Chinese female speakers after receiving instructions on the purpose of recording the Mandarin words ending in 7 distinct vowels: a[A], o[o], e[ɣ], ê[ɛ], i[i], u[u], and ü[y]. The audio were directly recorded into the computer, assigning a single file to each set of words from the sources. We used Praat software to extract the first (F1) and second (F2) formants from the data. Presenting the results in the form of numerical tables. The study's findings indicate a significant difference in their voice quality, despite the fact that they are all Chinese. Specifically, they produced the highest formant value for the single vowel [A] in the word "*pà*," and the longest duration for a Chinese female's pronunciation of the single vowel /o/ was 0.438750 seconds in the word "*bo*." Meanwhile, the pitch score was lowest for both native speakers and is found in the single vowel /u/ in the word 须 "*Xue*." The effect of pitch errors is one factor that affects the resulting formant and duration value.

Keywords: *Mandarin Single Vowel, Phonetics, Praat, Acoustic Formant Measurement*

1. Introduction

Language, as a combination of sound and meaning, serves as a fundamental tool for human communication. Mispronunciation can lead to misunderstandings or even the inability to understand the speech of others, which highlights the importance of phonetic analysis in how speech sounds are produced and perceived. In today's society, where it is common for a person to speak two or three languages, accurate pronunciation and fluency are crucial skills for effective communication. In this rapidly advancing era, fluency and standardized Mandarin are increasingly important in everyone's daily life. Huang & Liao (2017) said that Mandarin is one of the dialects of Chinese alongside Shanghainese, Cantonese, Hakka, and many more. Mandarin, the most widely spoken dialect of Chinese and official language of China, is based on the phonetics of the Beijing dialect. Obviously, tone is one of the unique characteristics of the Mandarin speech system, which distinguishes it from another speech system.

The tone, also referred to as the pitch of the voice, primarily influences the quality of the voice. Focusing on the nature of vowels, the complex vibration of sounds primarily determines the timbre of the voice. Mandarin has four distinct tones, which set it apart from English. In other words, the same vowel may sound different because of the difference in tones; they are flat tone, rising tone, fall rising tone, and falling tone. A syllable can be pronounced in those four different ways, and each pronunciation has a different meaning. For instance, the word "*ma*" can mean "mother," "numb," "horse," or "scold," depending on which one of the four tones we use. The word "*guo*" can mean "pot," "country," "fruit," or "cross," depending on how we say it. Mushangwe (2013) stated that Mandarin is one of the world's hardest languages, as it is a vowel-rich language that uses tones to create numerous vowel sounds.

Vowels play an essential role in a syllable, often being the most pronounced part of it. It is because of vowels that people can perceive language and communicate with each other. Huang & Liao (2017) pointed out that “syllables” are phonetic segments composed of phonemes and are the smallest units of speech that people naturally feel when they listen to other people talking. In phonology, smaller phonetic units known as "phonemes" compose syllables. Jiang (2013) pointed out that “phonemes” are the smallest phonetic units divided from the perspective of timbre, such as “爸 (*bà*) daddy” in Mandarin can be divided into two different phonemes, “b[p]” and “a[A]”. We refer to the phoneme at the beginning of a syllable as the initial, and the one at the back of the syllable as the final. As in the above example, “b[p]” is the initial and “a[A]” is the final. However, in addition to initials and finals, phonetics also includes the concept of consonants and vowels. We won't delve into the differences between initials and consonants here. Many people fail to distinguish the differences between finals and vowels, treating them as equals, which has significantly impacted scientific research on phonetics. In reality, finals and vowels are two distinct concepts. "Vowels, such as a, o, e, i, u, etc., are phonemes that are formed by the airflow that vibrates vocal cords and pass through the mouth and throat without obstruction." Finals differ from vowels in that they consist not only of vowels, but also of combinations of vowels and consonants. For example, in the word “瞎 (*xiā*) blind," the final is only composed of a vowel, but in the word “甘 (*gān*) sweet," the final is composed of the vowel “a[a]” and the consonant "n[n]." To conduct phonetic research properly, it is crucial to distinguish between the concept of finals and vowels. In fact, the researcher has discovered that distinct tones in the pronunciation of vowels, particularly in the final vowel sound, alter the meaning.

Mandarin is an ideographic language. However, Chinese pinyin (Latin letters) marks the pronunciation of Mandarin characters. Therefore, like many languages in the world, Mandarin syllables consist of consonants and vowels. Single vowels Mandarin includes 7 linguistic vowels, 2 apical vowels, and 1 tongue-rolling vowel. These 7 linguistic vowels in Mandarin are a[A], o[o], e[ɤ], ê[ɛ], i[i], u[u], and ü[y], with distinct formant frequencies based ontongue height and backness (Soekarto et al, 2019). Mao (2008) noted that three dimensions generally classify vowels: the height of the tongue, the front and back of the tongue, and the roundness of the lip. From the perspective of the height of the tongue, there are high vowels (i, u, ü), semi-high vowels (e, o), semi-low vowels (ê), and low vowels (a); from the perspective of the front and back of the tongue, there are front vowels (i, ü), central vowels (e[ə]), and post vowels (u, o); and from the perspective of roundness of the lip, there are round lip vowels (ü, u, o) and non-round lip vowels (i, a). The pronunciation of Mandarin Chinese linguistic vowels is shown below:

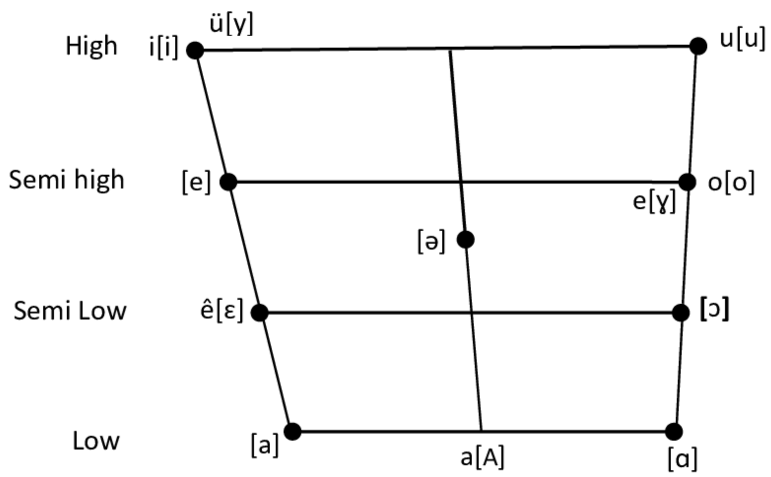

Figure 1. Mandarin Chinese Linguistic Vowels Tongue Map

In phonetics, formant analysis has been widely used to study the articulatory and acoustic properties of vowels. As noted by Clark and Yallop (1995), formants represent the resonant frequencies of the vocal tract, which are shaped by the position and movement of articulators such as the tongue, lips, and jaw. This theoretical foundation underpins the methodology employed in this study, demonstrating the relevance of acoustic measurements in understanding speech production. The study of formant analysis is highly relevant to deepen the understanding of acoustic differences between languages, particularly between Mandarin and other language. We can use formant measurement to quantify the production of speech sounds in connected speech, with the aim of better understanding the articulation of speech sounds. Here, our focus is on the form and duration of a single vowel in the Mandarin language.

We conducted this analysis using an acoustic phonetics study and the PRAAT software. Praat is a very flexible tool to do speech analysis. According to Muharami & Muliadi (2019), the use of Praat allows for the visualization and quantification of speech data, making it an invaluable tool in phonetic research, especially for tonal languages like Mandarin. The integration of such tools in linguistic studies not only enhances the accuracy of data analysis but also supports the development of applications in language teaching, speech therapy, and voice recognition technology.

From previous studies; Soekarto et al. (2019) examined constrictive phonological features between Chinese and Indonesian, yet their study did not explore formant frequency in depth. Mushangwe (2013) compared Chinese and Shona vowels but did not provide detail analysis of Mandarin single vowels using acoustic measurements. Muharami & Muliadi (2019) employed Praat software to analyze vowel but not in Mandarin vowels. Therefore, this study focused on analyzing the formant of Single Vowels in Mandarin. By utilizing Praat, this study aims to provide an objective and detailed analysis of Mandarin vowels, offering insights into the acoustic properties of one of the world's most complex phonetic systems. To be specific, this study aims to analyze formant frequencies and durations of Mandarin single vowels using Praat.

2. Method

This study employed a descriptive qualitative method, which was grounded in the phenomena observed among native Mandarin speakers. We used the numerical results to describe the vowel quality, observing the frequency of the first formant (F1) and second formant (F2) in the pronounced phonemes. The participant in this study was five Chinese female speakers of Mandarin, aged between 20 and 40. The decision to focus on female participants within a specific age range was intended to reduce variability caused by physiological differences across genders and age groups. Focusing on female speaker within a specific age range allowed for more consistent comparisons of formant frequencies and vowel duration.

The materials were seven single vowel sounds in Mandarin Language, including a [A], o [o], e [ɣ], ê [ɛ], i [i], u [u], and ü [y]. The provided words, which are composed of seven single vowels in Mandarin, are as follows:

Table 1. Word List

Chinese Single Vowel	a[A]	o[o]	e[ɣ]	u[u]	ê[ɛ]	i[i]	ü[y]
Chinese word	怕	伯	乐	须	叶	踢	绿
Pin – yin	*pà*	*Bó*	*Lè*	*Xū*	*Yè*	*Tī*	*Lǜ*
	Afraid	Uncle	Happy	Should	Leave	Kick	Green

All participants, using a recording application on their smartphones, uttered those words in their original voices. Participants were instructed to conduct the recording process in controlled environments with minimal background noise to minimize external variables that might interfere the results. The voices then converted to WAV format with sampling rate of 44100. Hz. Through this process, the data has good quality.

The recording were analyzed using Praat software. The use of Praat software in this study, as highlighted by Boersma and Weenink (2019), provides researchers with a powerful tool to analyze the fine details of speech sounds, enabling precise measurements of formant frequencies and durations. It identified the pitch, formant, and spectrogram values. Helped reseachers in analyzing the formant, especially for tonal languages like Mandarin. Next, the recording was extracted to the Praat. Using the view and edit function in the Praat software, both the waveform and the spectogram of the recording were displayed. The waveform allowed researchers to visualize the overall amplitude of the speech signal and the spectogram provided a detailed representation of frequecy.

Clark and Yallop (1995) stated the standard procedures in acoustic phonetics, the values of F1 and F2 were extracted at the temporal midpoint of the vowel to reduce the influence of transitional from surrounding consonants. The unit of measurement for formants is Hertz (Hz). Meanwhile, the vowel duration was measured by identifying the onset and offset of the vowel segment within the spectogram. Which is showed by Praat automatically. The first step done by the researcher is the analysis of each word pronounced by the speaker as provided in the table to see the formant measurement between five Chinese female speakers.

3. Result and Discussion

This process is crucial to the study. The Praat application enables the identification of pitch, formant, and spectrogram values in each sound recording. But here the researcher focused on formant in some single vowel. The first stage resulted in the recording of files in WAV format, each containing a single vowel from a speaker. Mandarin language is an ideographic language. Chinese pinyin (Latin letters) marks the pronunciation of Mandarin characters. Therefore, like many languages in the world, Mandarin syllables consist of consonants and vowels.

Single vowels Mandarin includes 7 linguistic vowels, 2 apical vowels, and 1 tongue-rolling vowel. These 7 linguistic vowels in Mandarin are a[A], o[o], e[ɤ], ê[ɛ], i[i], u[u], and ü[y]. Mao (2008) noted that three dimensions generally classify vowels: the height of the tongue, the front and back of the tongue, and the roundness of the lip. From the perspective of the height of the tongue, there are high vowels (i, u, ü), semi-high vowels (e, o), semi-low vowels (ê), and low vowels (a); from the perspective of the front and back of the tongue, there are front vowels (i, ü), central vowels (e[ə]), and post vowels (u, o); and from the perspective of roundness of the lip, there are round lip vowels (ü, u, o) and non-round lip vowels (i, a). Also, based on the Syarfina et al. (2024), F1 is related to high vowel tones, while F2 is related to the dimensional representation of front or back vowel tones. Based on the Chinese female sound, there are some records in the form of WAV and transferred into Praat software in order to get the formant value. The formant values for each participant are listed below.

Table 2. Formant values of Participant 1

Chinese Single Vowel's Nova	a[A]	o[o]	e[ɤ]	u[u]	ê[ɛ]	i[i]	ü[y]
Chinese word Pin –yin	怕 *pà* Afraid	伯 *Bó* Uncle	乐 *Lè* Happy	须 *Xū* Should	叶 *Yè* Leave	踢 *Tī* Kick	绿 *Lǜ* Green
F1	796	480	603	429	601	462	437
F2	1335	1012	1546	2768	2420	3212	2508

From the table above, the highest formant (F1) of participant 1 is single vowel [A] for the word 怕 *pà*, showed 796 Hz. Consistent with its classification as a low vowel. Meanwhile, the lowest formant (F1) is a single vowel [y] for the word 绿 Lǜ, showing 437 Hz. It is reflecting its high tongue position. Below is the spectrogram for participant 1 that had the highest single vowel (F1) for the word 怕 *pà* 796 Hz and 0,179938 seconds for the duration.

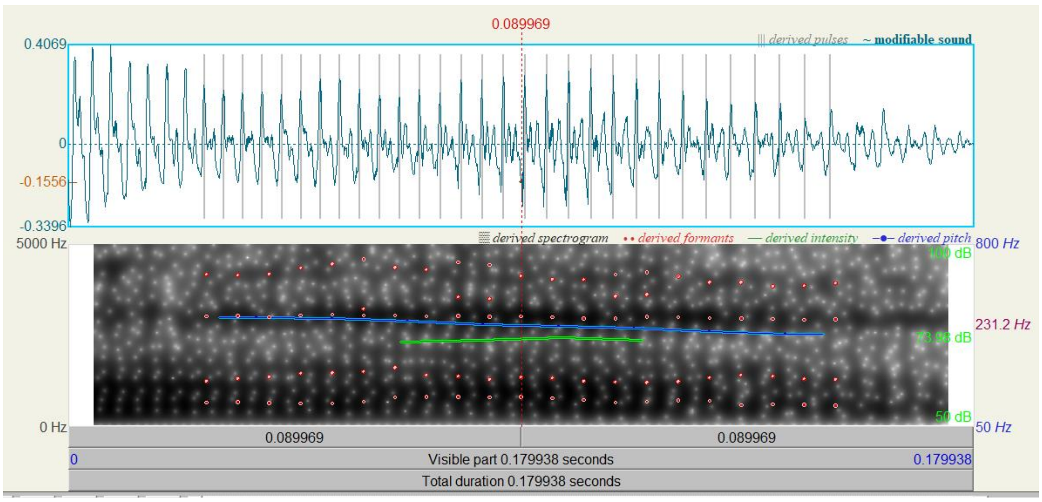

Figure 2. Spectogram for the highest formant Participant 1

Table 3. Formant values of Participant 2

Chinese Single Vowel’Jacqueline	a[A]	o[o]	e[ɣ]	u[u]	ê[ɛ]	i[i]	ü[y]
Chinese word Pin – yin	怕 *pà* Afraid	伯 *Bó* Uncle	乐 *Lè* Happy	须 *Xū* Should	叶 *Yè* Leave	踢 *Tī* Kick	绿 *Lǜ* Green
F1	991	720	689	397	509	432	317
F2	1485	1314	1352	2948	2475	2759	1202

For participant 2, single vowel [A] for the word 怕 *pà* again showed the highest formant (F1) for 991 Hz. The formant (F2) showed vowel [u] for word 须 *Xū* was extremely high. it showed 2948 Hz. This deviataion may indicate individual articulatory habits, as rounded vowels are sometimes produced with less backing. Below is the spectrogram for participant 2 that had the highest single vowel (F1) for the word 怕 *pà* 991 Hz and 0,264437 seconds for the duration.

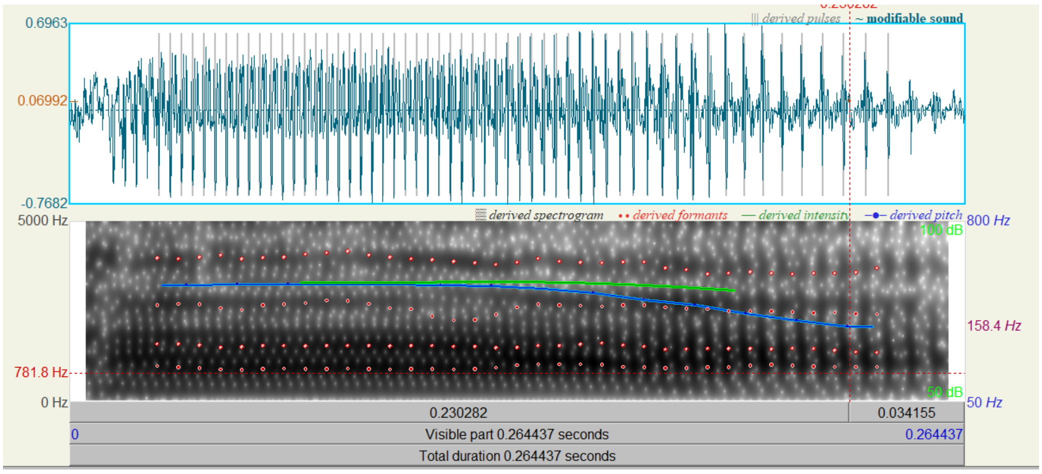

Figure 3. Spectogram for the highest formant Participant 2

Table 4. Formant values of Participant 3

Chinese Single Vowel’ Sherly	a[A]	o[o]	e[ɣ]	u[u]	ê[ɛ]	i[i]	ü[y]
Chinese word Pin – yin	怕 *pà* Afraid	伯 *Bó* Uncle	乐 *Lè* Happy	须 *Xū* Should	叶 *Yè* Leave	踢 *Tī* Kick	绿 *Lǜ* Green
F1	942	629	744	349	704	405	307
F2	1109	891	1702	2415	2217	2011	1502

Participant 3 showed a result similar to the previous participants, with the highest formant (F1) corresponding to a single vowel [A] for the word 怕 *pà*. The (F1) showed 942 Hz, again confirming its low vowel. Vowel [y] for the word 绿 *Lǜ* showed the lowest (F1) with 307 Hz. Below is the spectrogram for participant 3, who had the highest single vowel frequency for the word 怕, 942 Hz, with a duration of 0,195306 seconds.

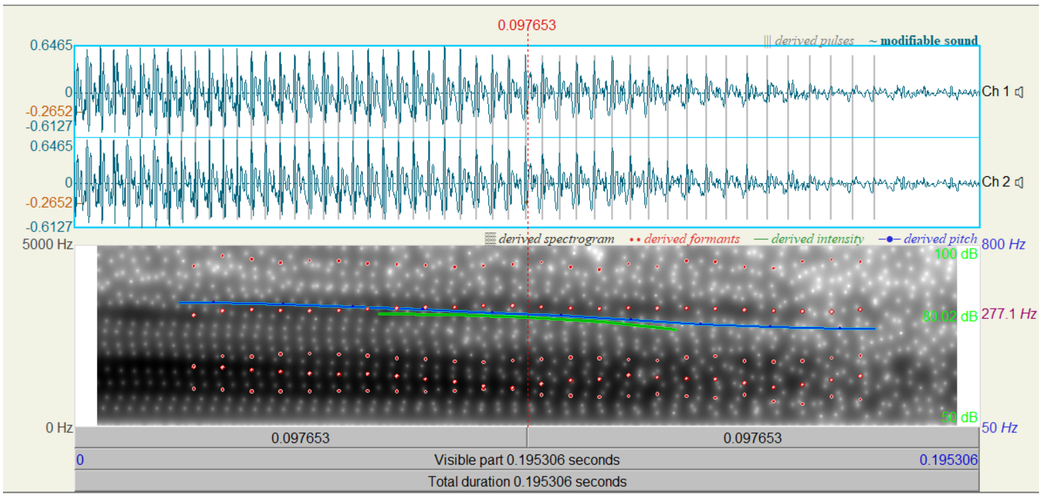

Figure 4. Spectrogram for the highest formant Participant 3

Table 5. Formant Values Participant 4

Chinese Single Vowel'Elice	a[A]	o[o]	e[ɤ]	u[u]	ê[ɛ]	i[i]	ü[y]
Chinese word Pin – yin	怕 *pà* Afraid	伯 *Bó* Uncle	乐 *Lè* Happy	须 *Xū* Should	叶 *Yè* Leave	踢 *Tī* Kick	绿 *Lǜ* Green
F1	868	700	784	522	775	489	378
F2	1690	1087	1625	2678	1558	3018	1558

Again, Participant 4 showed that the highest formant (F1) is a single vowel [A] for the word 怕 *pà*. The (F1) showed 868 Hz. For (F2), vowel [i] for the word 踢 *Tī* showed 3018 Hz, showing a strong front vowel articulation. Compared to other participants, this participant uttered words with relatively greater mid-vowel openness, which may reflect dialectal or individual variation. Below is the spectrogram for participant 4, who had the highest single vowel frequency for the word 怕, 868 Hz, with a duration of 0,161859 seconds.

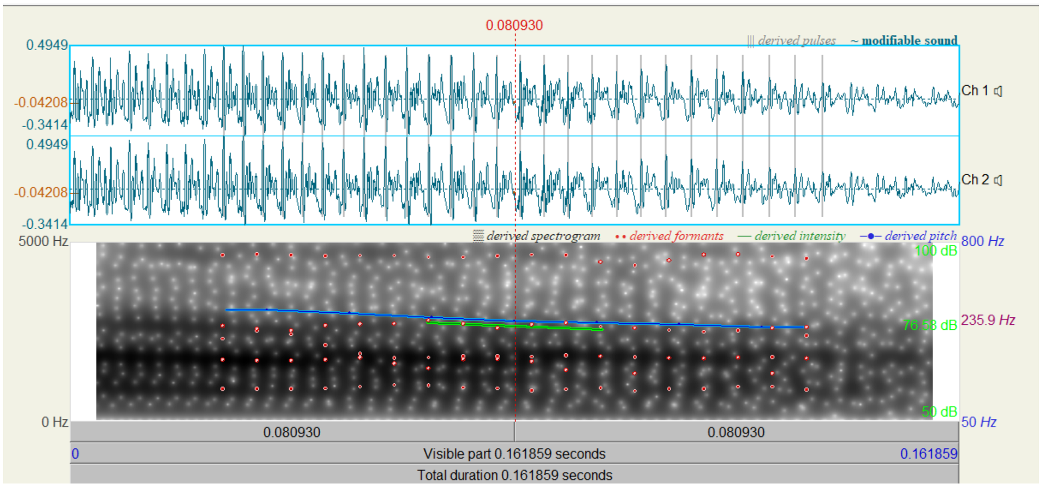

Figure 5. Spectrogram for the highest formant Participant 4

Table 6. Formant Values Participant 5

Chinese Single Vowel'Quinn	a[A]	o[o]	e[ɤ]	u[u]	ê[ɛ]	i[i]	ü[y]
Chinese word Pin – yin	怕	伯	乐	须	叶	踢	绿

	pà Afraid	*Bó* Uncle	*Lè* Happy	*Xū* Should	*Yè* Leave	*Tī* Kick	*Lǜ* Green
F1	991	720	689	397	509	432	317
F2	1485	1314	1352	2948	2475	2759	1202

The last participant also showed consistent results, with the highest formant (F1) being single vowel [A] for the word 怕 pà, and the lowest formant (F1) being single vowel [y] for the word 绿 *Lǜ*. Each (F1) showed 991 Hz and 317 Hz. Below is the spectrogram for participant 5, who had the highest single vowel for the word 怕 *pà* 991 Hz and 0, 15426 seconds for the duration.

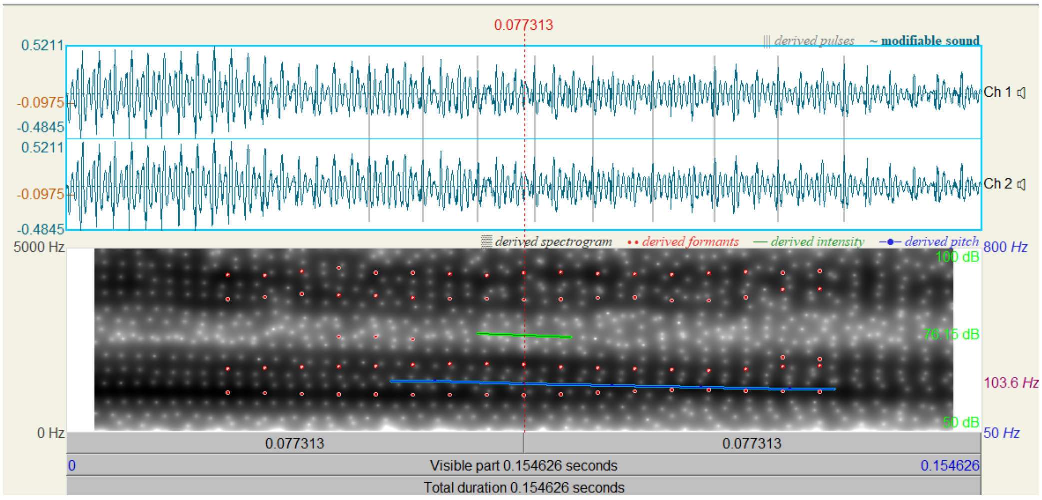

Figure 6. Spectrogram for the highest formant Participant 5

Table 7. The average of Formant (F1) and (F2)

Chinese Single Vowel	a[A]	o[o]	e[ɣ]	u[u]	ê[ɛ]	i[i]	ü[y]
Chinese word Pin – yin	怕 *pà* Afraid	伯 *Bó* Uncle	乐 *Lè* Happy	须 *Xū* Should	叶 *Yè* Leave	踢 *Tī* Kick	绿 *Lǜ* Green
F1	917	649	584	418	619	444	351
F2	1420	1123	1515	2751	2229	2751	1594

From the data above, the single vowel [A] for the word 怕 pà has the highest formant (F1) at 917 Hz on average among all of the single vowels. And vowel [y] for the word 绿 Lǜ has the lowest formant at 351 Hz on average. The measurement results showed consistent patterns among the five participants. Start from participant 1, the highest formant showed by vowel [A] for the word 怕 pà, and the lowest formant showed by vowel [y] for the word 绿 Lǜ. As Mao (2008) noted, the three dimensions generally classify vowels. The vowel [A], as a low vowel, is produced with the tongue positioned lower in the oral cavity, which naturally increases the first formant (F1) frequency. Meanwhile, [y] is a high front rounded vowel, articulated with a high tongue position and lip rounding, resulting in a very low first formant (F1).

Table 8. The Average Duration

Chinese Single Vowel	a[A]	o[o]	e[ɣ]	u[u]	ê[ɛ]	i[i]	ü[y]
Chinese word Pin – yin	怕 *pà* Afraid	伯 *Bó* Uncle	乐 *Lè* Happy	须 *Xū* Should	叶 *Yè* Leave	踢 *Tī* Kick	绿 *Lǜ* Green
Duration	0. 191242	0. 438750	0. 195375	0.429375	0.149313	0. 396313	0.257563

From the data above, we can see that the vowel [o] for the word 伯 Bó exhibits the longest duration for 0. 438750 seconds. Meanwhile, the vowel [ɛ] for the word 叶 *Yè* exhibits the shortest duration for 0.149313 seconds.

Focusing on both formant frequencies and vowel durations, the highest formant value was consistently observed in the pronunciation of the vowel [A] for the word 怕 *pà*,' which aligns with its classification as a low, open vowel. This observation underscores the relationship between tongue height and formant frequencies, a fundamental principle in phonetics. Conversely, the vowel [y] 绿 *lǜ* exhibited the lowest formant values, reflecting its high, back articulation and illustrating the acoustic impact of tongue positioning. It also identified significant variation in vowel duration, with [o] for the word 伯 *Bó* showing the longest average duration across participants. This finding suggests that the articulation of rounded vowels may involve more complex motor control, leading to longer durations.

These results emphasize the role of articulatory settings in determining acoustic characteristics, which is consistent with the theoretical framework established by Clark and Yallop (1995). The longer durations observed in certain vowels may also be attributed to the influence of Mandarin's tonal system, where tonal pitch contours require precise control of vocal fold vibration and airflow during vowel articulation. This observation aligns with findings from Huang & Liao (2017), who noted that tonal languages often show subtle variations in vowel properties due to the dual function of pitch in conveying tone and influencing vowel quality. Overall, the study provides not only confirmation of the theoretical expectations but also empirical evidence of the speakers' variations. These findings contribute to the limited literature on Mandarin single vowels and highlight the importance of acoustic phonetics analysis in capturing both universal and individual features of speech.

4. Conclusions

In summary, the formant analysis of single vowel in Mandarin spoken by Chinese speaker can be concluded that single vowel with the highest formant 1 is when the respondent pronounced the word with single vowel [A] for the word 怕 *pà* (afraid) and the lowest is when the respondent pronounced the word with single vowel [y] for the word 绿 *Lǜ* (green), and sound pronunciation of single vowel /o/ is the longest duration value from Chinese female for 0. 438750 second for the word 伯 *Bó* (uncle). Meanwhile, the highest formant 2 is when the respondent pronounced the word with a single vowel 踢 Tī (kick), 须 Xū (should), and the lowest is when the respondent pronounced the word with a single vowel 绿 *Lǜ* (green). We can conclude that the lowest formant for f1 and f2 is the single vowel 绿 *Lǜ* (green). There are several differences in scores on single vowel pronunciation between native speakers due to the influence of pitch errors in pronunciation. Each vocabulary can also be a factor that influences the value of duration, pitch, and the resulting intensity. Complexity also adds a unique dimension to vowel articulation in Mandarin, as pitch not only defines tone but also subtly influences formant frequencies.

Additionally, this study underscores the complexity introduced by Mandarin's tonal system, where tonal variations not only affect lexical meaning but also subtly influence acoustic parameters such as formant frequencies and durations. The interplay between pitch and vowel quality, as highlighted in this research, further distinguishes Mandarin from non-tonal languages, adding a layer of intricacy to its phonetic structure. This observation echoes findings by Huang & Liao (2017), who emphasized the dual role of pitch in tonal languages as both a phonetic and phonological element. Furthermore, the use of Praat software has proven to be an effective tool for analyzing phonetic differences, providing valuable insights into the relationship between vowel quality, pitch, and duration. These insights have practical implications not only in phonetics but also in language teaching, particularly in helping non-native speakers achieve better pronunciation in Mandarin.

In summary, this study advances our understanding of the acoustic characteristics of Mandarin vowels and their interaction with tonal features. By leveraging tools like Praat, we can continue to uncover the complexities of speech production, contributing to both theoretical linguistics and practical applications. The findings of this research serve as a foundation for future studies, paving the way for deeper exploration into the fascinating interplay of language, sound, and meaning. In the future, similar analysis can be extended to compare vowels in other languages to explore universal and unique characteristics of each language.

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