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The realization of lexical tones in Sichuan opera[1]

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Abstract

The tonal-melodic relationship is essential in conveying the intended lyrical meaning in music of tonal languages. The new style of Chinese music, developed in the late 19th and early 20th centuries, tended to employ an ordinal scale to manage relationships between tone and melody. In contrast, the compositional principle of traditional Chinese opera incorporates an incomplete ordinal mapping, which only applies to tone sequences that ascend or descend. When a tone sequence is consistent, the melody direction will exhibit a falling pattern rather than remaining at a plateau. This paper presents an experimental investigation of the relationship between tone and melody in Sichuan opera, as well as an examination of listeners' technique for extracting lyrics. Through an opera analysis, we found that Sichuan opera aligns well with this traditional principle of composition. A perceptual experiment indicated that listeners utilize the mapping relationships prescribed by this composition principle to facilitate their extraction of lyrics. The adherence to the compositional principle in Sichuan opera ensures the musicality of the melody while retaining sufficient recognizability of lexical tones in the lyrics.

Keywords: Sichuanese lexical tone, musical melody, perception

1. Introduction

It is estimated that between 50% to 60% of the world's languages are tonal languages, where the meaning of a word is closely related to the pitch of that word (Yip, 2002). In these languages, tone is phonemic, therefore changing a word's pitch or pitch contour can drastically alter its meaning (Schellenberg, 2013). Meanwhile, pitch is one of the most important aspects of music. Therefore, the interplay between speech melody and song melody in tonal language songs, especially that in Chinese songs, has been of interest to scholars because of the close relationship between pitch and the meaning of tonal language. However, previous studies have mainly focused on popular songs in Standard Mandarin and Cantonese, and research on other Chinese dialects and traditional Chinese opera is scarce. In fact, the tonal-melodic mapping in traditional opera differs from popular songs, underscoring the need to explore the tone-melody relationship and how listeners extract the meaning of lyrics in this form of musical genre. Therefore, this study took Sichuan opera as a test case to examine its corresponding tone sequences, and conducted a perceptual experiment to explore the relationship between tone-melody interaction and listeners' perception. The research may also contribute to the body of studies on tone-melody mappings in traditional opera.

2. Literature review

2.1. Previous studies on tone-melody interaction in Chinese songs

The existing studies on the coordination of tone and tune in Chinese pop songs have mainly focused on Standard Mandarin and Cantonese. Despite both emerging as a new style of Chinese music during the late 19th and early 20th centuries (Mittler, 1997), the two musical genres employ distinct approaches to realizing linguistic tone. In Standard Mandarin songs, composers tend to ignore lexical intonation in their compositions, because Standard Mandarin has only four tones, which are not sufficient to form a complete scale (Chao et al., 1956). Therefore, Standard Mandarin pop songs have limited melodic representation of tones, with neither individual lexical tone contours nor tone target shifts being reflected in the melodic system (Ho, 2006). In contrast, composers could more easily include consonance in compositions of

Cantonese songs, as Cantonese has six tones that correspond more easily to the scale, and thus the tones in Cantonese songs are reflected in both structure and phonology (Schellenberg, 2013). However, the one-to-one correspondence between tone and pitch may not only make the song lose its musicality and bias it towards recitation, but also greatly limit the melodic span and the available intervals. Therefore, the corresponding tone sequence in Cantonese songs retains only the variation in the direction of the fundamental frequency (F_0) of the vocal tones in the lyrics (Wong & Diehl, 2002). For example, a higher pitch in speech can be realized as any higher F_0 in music, but never a lower F_0.

2.2. The realization of tone in traditional Chinese opera

The consonance of Cantonese songs is inherited from the pitch-fitting tradition in classical Chinese opera (Wong, 1997). Meanwhile, this tonal fit is also present in traditional opera in both Beijing Mandarin and other Mandarin dialects, though there is a tendency to separate the composition from the lyrics in the creation of popular songs at a later stage (Ho, 2006). This composition principle of consonance in traditional Chinese opera is called "*yi zi xing qiang* (Tunes Following Lyrics)" (Miao et al., 1985).

Sun (1983) summarized seven rules of the principle "Tunes Following Lyrics" using Beijing opera as an example. These seven rules defined the direction of melodic change in Beijing opera under seven different tonal variations of the lyrics (six cases in which the four Standard Mandarin tones are arranged in two pairs and one case of consistency) (see ***Table 1***). By further organizing this principle, it can be found that in the Beijing opera, the lexical tones can be arranged, from the highest to the lowest according to their corresponding melodies, in the following order: Tone 1, Tone 4, Tone 2, and Tone 3.

Table 1: "Tunes Following Lyrics" principle in Beijing opera (Sun, 1983)

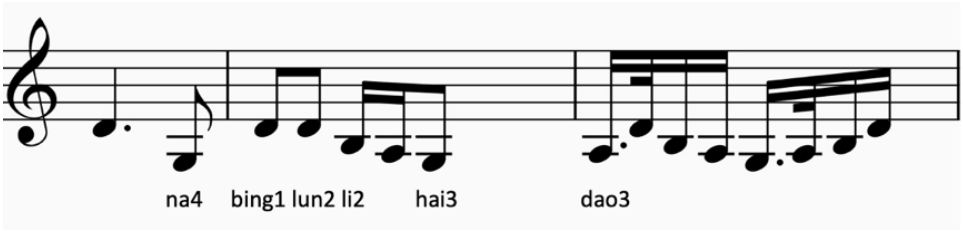
		Tone of the first character			
		1	2	3	4
Tone of the second character	1	+	-	-	-
	2	+	+	-	+
	3	+	+	+	+
	4	+	-	-	+

"+" means the first character corresponds to the higher pitch of the melody.

"-" means the second character corresponds to the higher pitch of the melody.

An example of this principle is presented in ***Figure 1***, an excerpt from /ba4 wang2 bie2 ji1/ (Farewell My Concubine). The first character is /na4/ in Tone 4 followed by /bing1/ in Tone 1. As Tone 1 should correspond to a melodic pitch higher than Tone 4 according to the principle, the two notes that are associated with these two characters are G followed by D, which is seven semitones higher than it.

Figure 1: An excerpt from /ba4 wang2 bie2 ji1/ (Farewell My Concubine) (Jin, 2006)



Furthermore, the principle of "Tunes Following Lyrics" can be outlined by combining the Standard Mandarin tones in five-level tone marks (***Table 2***). First, of the two nearby characters, the melodic pitch of the character with the higher starting pitch is higher than that of the other character. For instance, the melodic pitch of the character in Tone 1 is higher than that of Tone 2. Second, if the starting pitch is the same (e.g., Tone 1 and Tone 4), then the ending pitch levels are compared (so that Tone 1 has a

higher melodic pitch than Tone 4). Third, if two characters have the same tone, the melodic pitch of the first character is higher than the melodic pitch of the second word.

Table 2: The Standard Mandarin tones in the five-level tone marks

Tone	1	2	3	4
Tone pitch	55	35	214	51

Besides, the principle does not emphasize that the change in melodic pitch should be consistent with the change in tone in terms of the magnitude of the variation, so the corresponding tone sequences in Chinese traditional opera, like those in Cantonese songs, retain only the change in the direction of F_0 in the lyrics. However, the ordinal mapping is only reserved when the tone sequence is rising or falling. When the tone sequence is consistent, the melody direction will manifest as falling instead of remaining plateaued. Thus, this principle can essentially be considered a partial ordinal mapping between musical and tonal sequences fit, except in the case of consonant tones.

However, the proportion of this tonal-melodic mapping is low in traditional Chinese operas according to current research. For example, Suzhou Tanci, a traditional Suzhou opera, was not in high concordance with the compositional principle (the degree was only 49%), because of the tone sandhi in Wu dialects (Yang, 2019, 2020). Besides, misheard lyrics in Beijing opera also occur frequently. This may be attributed to the fact that the tonal system of Beijing dialect has undergone many changes from its establishment in the early 20th century (Chen, 2018). Therefore, the current Standard Mandarin pronunciation may be different from the tones used at the time Beijing opera emerged, so using today's Standard Mandarin tones to identify the Beijing opera may cause mishearing. In contrast, there has been no significant change in the tone pitch in Sichuanese over the last 150 years (Endo & Ishizaki, 2015), which could potentially make Sichuan opera a better test case for tone-melody correspondence.

2.3. Listeners' perception of tone

According to the *Chinese music dictionary* (Miao et al., 1985), the purpose of the principle "Tunes Following Lyrics" is to make the meaning of the words clear to the listeners, thus the listeners' perception is also worth attention. The listeners can determine the meaning of a word by comparing the pitch of the preceding and following words, for instance Cantonese listeners use this to determine the meaning of words with ambiguous tones in short sentences (Wong & Diehl, 2002). However, it has also been shown experimentally that changing the tone in discourse was only as disruptive to the listeners as changing the segment in tonal language (Schirmer et al., 2005). Because the number of tonal minimal pairs in most tonal languages does not seem to be high, incorrect tones can usually be understood by ordinarily intelligent listeners, except in the fairly few cases where differences in tone do involve differences in meaning (Ward, 1932). Although there is no consensus on whether phonemic divergences have an effect on comprehension, given that Cantonese songs typically adhere to ordinal mapping and are thereby more comprehensible (Schellenberg, 2013), the ordinal mapping may well help listeners identify lyrics. Moreover, the melodic downward movement corresponding to a consistent tone sequence in traditional Chinese opera may also align with listeners' perception of lyrics, given the gradual decrease in pitch from the start to the end of an utterance in most languages, known as "downdrift" (Fromkin & Ohala, 2014). A perceptual experiment demonstrated that listeners anticipate a higher F_0 in the initial tone of a discourse compared to the final tone, even if both tones are identical (Wong, 1999). Therefore, as the tone-melody mapping prescribed by the compositional principle is consistent with people's discourse recognition, listeners may employ this mapping relationship to retrieve lyrics.

In addition, the ability of lyric recognition may also be related to the listeners' age, native language, gender, and regional accents. Age-related cognitive decline is an important human experience (Deary et al., 2009). Some musical tasks reflected the same age-related decline as non-musical tasks (Halpern & Bartlett, 2002). However, it has also been shown that in music perception, experience differences are greater than age differences, and in some cases, age differences do not even exist (Dowling et al., 2008). Thus, experience and exposure to specific music genres may mitigate age-related

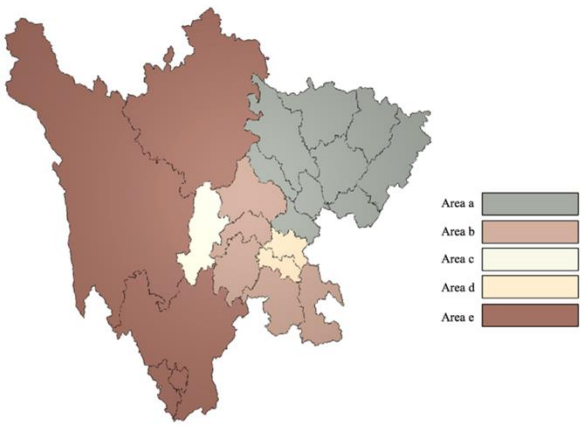
declines in lyric recognition. The audience of Sichuan opera is mainly the older generation, aged between 50 and 80 years old (Wang, 2023). Therefore, as listeners age, they are more likely to be exposed to Sichuan opera and become more familiar with its lyrics.

In terms of language proficiency and cultural background, research has shown a link between music and native language proficiency (Ludke et al., 2013). People are shown to have an advantage in verbal memory through music, especially in word-by-word recall tasks (Dowling et al., 2001). Therefore, native speakers may be more accurate in identifying the lyrics of their own regional operas than non-native speakers.

For gender differences in language processing, a study has shown that women are generally better than men at recognizing and recalling verbal information, and that this difference was more pronounced in participants aged 66-89 years (Bleecker et al., 1988). Therefore, based on the cognitive commonality between music and language, the female advantage in language processing may result in women outperforming men in music cognition (Miles et al., 2016).

Besides, regional accent differences exist within Sichuanese (Li, 2009), which may also affect listeners' recognition of Sichuan opera lyrics. Sichuan is divided into five accent areas based on vocal tones (***Figure 2***): a) most of the eastern part of Sichuan, b) along the Minjiang River basin, c) among areas a, b, and e, d) between areas a and b, and e) the minority gathering places in western Sichuan (Sun, 2011).

Figure 2: Sichuanese accent areas



The main differences among them are the entering tone, the retroflex consonant, the palatalization of alveolar plosive, and the influence of other ethnic languages (***Table 3***). The entering tone are found only in Area b (Yang, 1984). Except for Area a and Area c, all other areas have the retroflex consonant (Sun, 2010). The palatalization of alveolar plosive is only found in Area c (Sun, 2011). In addition, only Area e is influenced by other ethnic languages (Li, 2009).

Table 3: The accent areas in Sichuanese

	a	b	c	d	e
Entering tone		√			
Retroflex consonant		√		√	√
Palatalization of alveolar plosive			√		
Influence of other ethnic languages					√

Since Sichuan opera is mainly popular in the eastern and central regions of Sichuan (Quan, 2019), namely Area a and northern part of Area b, people from these areas may have a higher chance of being exposed to Sichuan opera and learning its lyrics. Therefore, listeners from other areas, including most of the Area b, may be less accurate in identifying Sichuan opera lyrics.

2.4. Hypotheses

In this study, we present six hypotheses regarding the factors influencing the recognizability of Sichuan opera among listeners:

H1: Sichuan opera possesses a higher concordance with the compositional principle than Suzhou Tanci (49%).

H2: The concordance degree of the compositional principle is positively correlated to the accurate recognition of lyrics in traditional Chinese opera.

H3: Lyrics recognition accuracy is positively correlated with the age of listeners.

H4: Native speakers of Sichuanese have a higher rate of correct recognition than non-native speakers.

H5: The correct rate of recognition is higher for females than for males.

H6: Native speakers from Area a have higher correct rates than native speakers from other areas.

The first hypothesis (H1) was based on the observation of limited diachronic variation in the tones of Sichuan Mandarin (Endo & Ishizaki, 2015), which suggested that Sichuan opera may adhere more closely to the prescribed tonal-melodic mapping of composition principles. In the second hypothesis (H2), we assumed that adherence to the composition principle would result in heightened recognizability of Sichuan opera among listeners, as its primary purpose is to facilitate comprehension of lyrical content (Miao et al., 1985). The third hypothesis (H3) posited that increasing age may lead to greater exposure to Sichuan opera (Wang, 2023), resulting in better familiarity with its lyrical content. Hypothesis four (H4) was grounded in prior research showing that native speakers may exhibit greater accuracy in recognizing the lyrics of their regional operas compared to non-native speakers (Ludke et al., 2013). Hypothesis five (H5) was based on the finding that superior language processing abilities of females may confer a cognitive advantage in music perception (Miles et al., 2016), potentially resulting in better performance compared to males. Lastly, the sixth hypothesis (H6) suggested that geographical location may be a factor in recognition accuracy, as residents from Area A are more likely to become familiarized with its lyrics (Quan, 2019).

3. Methodology

3.1. Opera analysis

3.1.1. Material

To study the tone-melody mapping in Sichuan operas, 30 pieces of Sichuan opera were chosen as material (Wen, 1997). The selection of the 30 samples was based on the composition classification method proposed by Wen (1997), in which the 364 extant Sichuan operas were categorized through the characteristics of their musical melody

types, and finally summarized into ten major categories. Then three pieces in each tune category were randomly selected. These three pieces were sung in three different moods respectively, encompassing all three "personalities" of Sichuan opera (Wen, 1997).

3.1.2. Analysis

Based on the characteristics of Beijing opera (in **2.2.**), the features of Sichuan opera can be inferred. According to the tones of Sichuanese (***Table 4***), the sung word tones in Sichuan opera can be arranged from high to low according to their corresponding melodic pitches, which are: Tone 1, Tone 3, Tone 4, and Tone 2.

Table 4: Tone pitch in Sichuanese (Wang et al., 1986)

Tone	1	2	3	4
Tone pitch	55	21	53	213

With reference to the analysis of Cantonese songs (Wong & Diehl, 2002), the number and percentage of a series of notes associated with a series of tones, both of which were expressed according to the presence and direction of pitch changes (i.e., up, down, same), were calculated. The lyric tones and the melodies corresponding to the lyrics (with the last note utilized in cases where a character encompassed multiple notes) were transcribed separately to designated structural specifications and form a data set. The data set was processed by a Python program (see ***Appendix 1***) to obtain the frequency of the compliance of composition principle between musical and tonal sequences for Sichuan opera.

3.1.3. A pilot study in Beijing opera

Since there are limited Chinese traditional opera data available, 15 pieces of Beijing opera were chosen for comparison. As the most renowned traditional Chinese opera, Beijing opera may more accurately embody the tonal-melodic mapping relationship inherent in traditional Chinese opera compared to Suzhou Tanci.

Furthermore, given that the principle "Tunes Following Lyrics" are described and summarized using Beijing opera as a model (Sun, 1983), the conformity exhibited by Beijing opera with this principle may be more instructive.

These 15 Beijing operas were randomly selected from *100 classical Beijing opera pieces* (Jin, 2006). According to the principle of composition for Beijing opera summarized by Sun (1983), the lexical tones of lyrics can be ordered based on their corresponding melodies, with Tone 1 occupying the highest position, followed by Tone 4, Tone 2, and finally Tone 3, the lowest tone. Subsequently, as in the analysis of Sichuan opera, the number and proportion of a sequence of notes that corresponded to a sequence of tones, taking into consideration the direction and presence of pitch variations were computed. The tonal patterns of the lyrics and their corresponding melodies were documented and transcribed according to predetermined structural criteria to form a comprehensive dataset. Thereafter, the same Python program (refer to ***Appendix 1***) was employed to process the dataset and derive the frequency distribution of the adherence to compositional principle between musical and tonal sequences for Beijing opera.

Table 5 displays the tone-melody correspondence data for the selection of 15 Beijing operas. It is noteworthy that Down-Same is a compliant case instead of Down-Down, as the traditional composition principle does not fully adhere to an ordinal mapping. When the tone sequence is consistent, the melody direction will manifest as falling. The values enclose in parentheses represent the proportion of occurrences relative to the overall number of cases enumerated in the matrix. The 15 Beijing operas exhibited a 46.17% compliance rate with composition principle (as indicated by the cumulative values in the shaded cells of ***Table 5***).

Table 5: Number of tone-melody relation in Beijing opera

		Musical sequence		
		Up	Down	Same
Tone sequence	Up	125 (18.80%)	87 (13.08%)	40 (6.01%)
	Down	89 (13.38%)	96 (14.44%)	48 (7.22%)
	Same	51 (7.67%)	86 (12.93%)	43 (6.47%)

The compliance rate with composition principle (sum of grey cells) = 46.17%

The result indicated that the adherence to the composition principle in Beijing opera is below 50% as in Suzhou Tanci. This outcome may be traced back to the numerous modifications that the tone system of Beijing Mandarin has undergone since its inception in the early 20th century (Chen, 2018). Consequently, the current standard Mandarin pronunciation may diverge from the vocal tones employed during the formative stages of Beijing opera. As a result, utilizing standard Mandarin vocal tones to recognize the lyrics of Beijing opera may be susceptible to inaccuracies. Therefore, Beijing opera may not be a suitable sample of greater adherence to the composition principle for the perception experiment.

3.2. Perceptual experiment

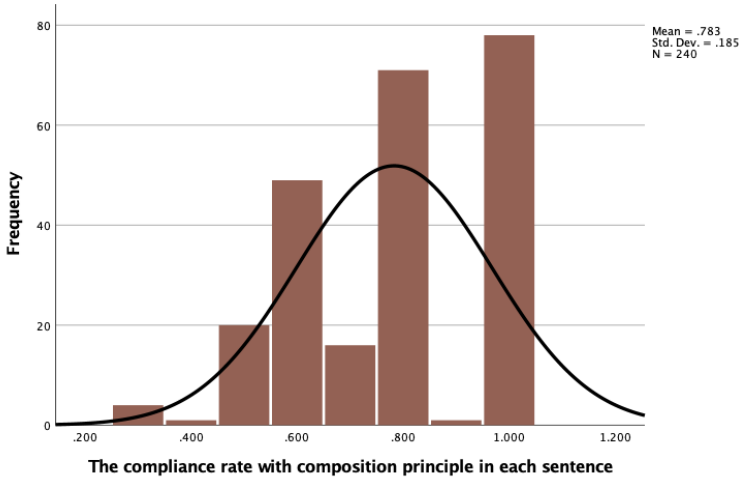
3.2.1. Stimuli

A perceptual experiment was then conducted to test whether the adherence to the composition principle in Sichuan opera affected the correct recognition of lyrics by listeners. This experiment followed the design of Wong and Diehl's (2002) perception experiment, with some modifications. Instead of using a carrier phrase that can carry all potential words, musical segments were directly chosen from a Sichuan opera excerpt sung by a professional Sichuan opera singer.

As the short-term memory span of sentences that can be discriminated acoustically is from six to seven characters (Yu et al., 1985), stimuli were chosen to be seven-character sentences (with six sets of tonal-melodic correspondence changes). In

addition, according to the frequency statistics of the sentence-based ordinal mapping of Sichuan opera in **3.1.1.** (statistics by a Python program in ***Appendix 2***), the frequency of tonal-melodic mapping of single sentences in Sichuan opera was concentrated above 50% (M = 0.783, SD = 0.185, see ***Figure 3***). Therefore, the compliance rates with composition principle of chosen stimuli were 100%, 83.3%, and 66.7%, namely among the six sets of correspondences, there are six, five, and four sets of tone-melody mapping with the compliance of composition principle respectively.

Figure 3: The compliance rate with composition principle in each sentence



Three sentences were chosen from each scale to compose nine original stimuli. All the stimuli were from a same piece of Sichuan opera, sung by a professional Sichuan opera singer. These nine original samples were then resynthesized by the pitch-synchronous overlap and add (PSOLA) method in Praat (Moulines & Laroche, 1995) to obtain samples of the musical variant of the original sample at the other two scales. This controlled the variables and ensured a high level of naturalness of sound. For example, Sentence 2 (stimuli 2a) was a clip with 66.7% compliance rate with composition principle. Through pitch processing, the compliance frequency of composition principle was adjusted to 83.3% and 100% by Praat to obtain two variants of Sentence 2 (Stimuli 2b and 2c). The remaining sentences were followed by the same, and a total of 27 clips were obtained (see ***Table 6***). During synthesis, the pitch

adjustment strictly followed the pentatonic scale of Chinese music (C, D, E, G, A) without involving G and B to maintain the overall musicality.

Table 6: Stimuli sets

	66.7%	83.3%	100%
Sentence 1	**1a**	1b	1c
Sentence 2	**2a**	2b	2c
Sentence 3	**3a**	3b	3c
Sentence 4	4a	**4b**	4c
Sentence 5	5a	**5b**	5c
Sentence 6	6a	**6b**	6c
Sentence 7	7a	7b	**7c**
Sentence 8	8a	8b	**8c**
Sentence 9	9a	9b	**9c**

Stimuli 1a, 2a, 3a, 4b, 5b, 6b, 7c, 8c and 9c were the original stimuli.

The rest were pitch-processed variant stimuli.

3.2.2. Experimental Task and Procedures

The perceptual experiment was conducted in the form of a questionnaire. The participants should understand Sichuanese and have normal hearing. Ethical approval was granted by EdUHK. Informed consents were obtained from all participants prior to the experiment.

The questionnaire contained two sections (see ***Appendix 3***). The first section was a language background survey, and the second section was the perceptual experiment. The language background survey focused on participants' age, gender, and use of Sichuanese. In the perception experiment, participants listened to nine music clips (random one variant stimuli of a sentence * nine different sentences), and then transcribed the lyrics from each of the nine sentences they hear by typing. They were told to write down exactly what they hear, without having to seek correct answers.

Unidentifiable and uncertain answers were acceptable, but participants were asked to write down the homophonic characters, or use Pinyin instead.

3.2.3. Data analysis

Listeners' perception accuracy was measured as a function of i) degree of adherence to the composition principle, ii) listeners' age, iii) native language, iv), gender and v) accent areas. The compliance of composition principle was adjusted by manipulating the melody trend. The listeners were divided into over-50 and under based on age, referencing the statistics of Wang (2023) on the audiences of Sichuan opera. The native language survey divided participants into native and non-native speakers of Sichuanese. The accent areas study focused on the differences in recognition ability of native speakers from the five different accent areas (in **2.3.**).

4. Result

4.1. Opera analysis

Table 7 shows the tonal-melodic correspondence in the 30 Sichuan operas. Both sequences are indicated by the presence and direction of pitch change (i.e., up, down, same). Notably, the traditional composition principle does not strictly adhere to an ordinal mapping, leading to Down-Same being a compliant case rather than Down-Down. The numbers in parentheses are the percentage of occurrences relative to the total number of cases included in the matrix. The frequency of compliance with composition principle occurred 76.90% of the time (the sum of the grey cells in ***Table 7***) in these 30 Sichuan operas.

Table 7: Number of tone-melody relation in Sichuan opera

		Musical sequence		
		Up	Down	Same
Tone sequence	Up	491 (32.78%)	34 (2.27%)	36 (2.40%)
	Down	41 (2.74%)	470 (31.37%)	32 (2.14%)
	Same	60 (4.00%)	191 (12.75%)	143 (9.55%)

The compliance rate with composition principle (sum of grey cells) = 76.90%

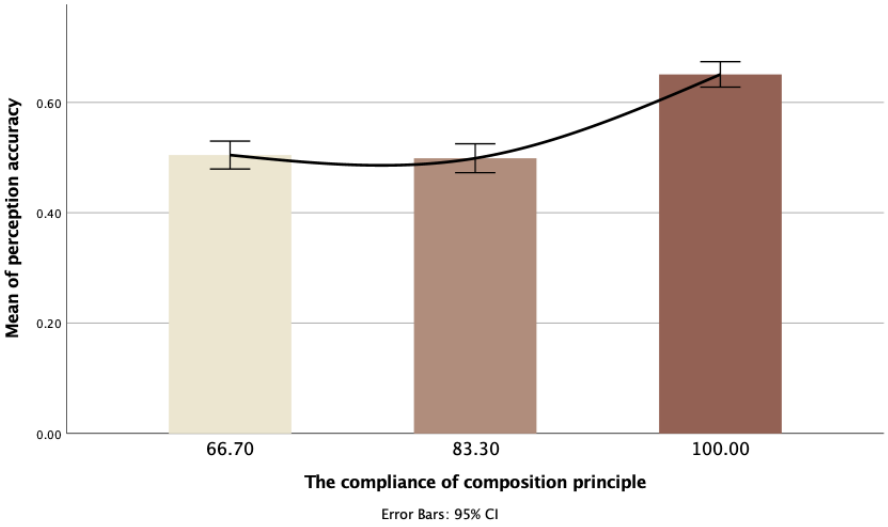
4.2. Perceptual experiment

4.2.1. The frequency of ordinal mapping

A one-way ANOVA was performed to compare the effect of three different frequency scales of the compliance of composition principle on listeners' perception accuracy. According to the test of homogeneity of variances, the result violated the assumption of homogeneity of variance, $p < 0.001$, therefore Welch test was conducted and showed a significant difference in the perception accuracy (***Figure 4***) between at least two groups, $F(2) = 49.772$, $p < 0.001$.

A post-hoc Tamhane test was performed to assess differences between the 3 groups of perception accuracy. The accuracy rates from 100% scale stimuli exhibited the highest average value in three scales ($M = 0.651$, $SD = 0.297$), which was higher than 83.3% scale ($M = 0.499$, $SD = 0.338$), and 66.7% scale ($M = 0.505$, $SD = 0.326$). Among them, 100% scale had significant difference with both 83.3% scale ($MD = 0.152$, $p < 0.001$) and 66.7% scale ($MD = 0.146$, $p < 0.001$), while there is no significant difference between 83.3% scale and 66.7% scale ($MD = -0.006$, $p = 1.000$).

Figure 4: Listeners' perception accuracy in 3 compliance scales



4.2.2. Age

An independence *t*-test was conducted to compare the effect of listeners' age on perception accuracy. On average, recognition accuracy was higher for listeners over the age of 50 (M = 0.580, SD = 0.110) than for those under 50 (M = 0.544, SD = 0.108), and this difference was significant, $t(212) = -1.983$, $p = 0.024$. Besides, this significant difference was also shown in the perception for only 100% scale stimuli, $t(212) = -2.409$, $p = 0.008$, where recognition accuracy of people over 50 ($M = 0.701$, $SD = 0.127$) was still higher than those under 50 (M = 0.638, SD = 0.162).

4.2.3. Native language

An independence *t*-test was performed to compare the effect of native language background on perception accuracy. Basically, native speakers of Sichuanese (M = 0.553, SD = 0.108) performed better in lyric recognition than non-native speakers (M = 0.521, SD = 0.130), though the difference was not significant, $t(212) = -1.023$, p = 0.154. This difference became significant in the perception for only 100% scale stimuli, $t(212) = 2.332$, $p = 0.010$, where native speakers' recognition accuracy ($M = 0.657$, SD = 0.155) was still higher than non-native speakers' ($M = 0.553$, $SD = 0.178$).

4.2.4. Gender

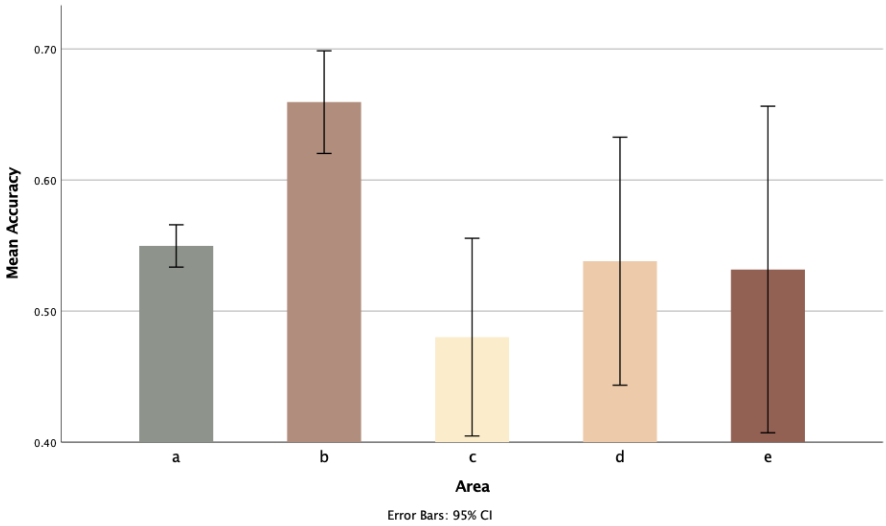
The effect of gender on perception accuracy was also tested by an independence *t*-test. Generally, male (M = 0.560, SD = 0.123) had a higher rate of correctness than female (M = 0.546, SD = 0.100), but this difference was not significant, $t(212) = -0.888$, $p = 0.188$. This advantage remained in the over 65 age group, with men (M = 0.652, SD = 0.105) continuing to have higher correct rates than women (M = 0.548, SD = 0.124), and the difference became significant, $t(17) = -1.989$, $p = 0.032$.

4.2.5. Accent areas

The effect of the accent difference from five areas on listeners' perception accuracy was tested by a one-way ANOVA. According to the test of homogeneity of variances, the result met the assumption of homogeneity of variance, $F(4) = 2.042$, $p = 0.090$, thus the ANOVA test was conducted. A significant difference in the perception accuracy (***Figure 5***) between at least two different accent areas was shown, $F(4) = 3.400$, $p = 0.010$.

A post-hoc Bonferroni test was performed to assess differences between the five groups of perception accuracy. The accuracy rate from Area b was the highest (M = 0.660, SD = 0.058), and had a significant difference with that from Area a (MD = 0.110, $p = 0.010$).

Figure 5: Listeners' perception accuracy in 5 accent areas (Y-axis starts at 0.40)



5. Discussion

5.1. A review of results

This study looked into how tones and melodies are connected in Sichuan opera and how listeners perceive this connection. The results showed that Sichuan opera closely follows the pattern of combining tones and melodies mandated by the compositional principles of traditional opera (H1). Also, listeners can more easily identify lyrics when the sung parts follow this pattern (H2).

The study put forward four ideas about the language background of the listeners. First, older listeners might recognize the lyrics more accurately (H3). Second, native speakers might have a higher recognition rate than non-native speakers (H4). The results agreed with both of these ideas. However, the study's ideas about gender and regional accents affecting recognition accuracy did not hold true. The study thought that women would be better than men at recognizing lyrics (H5), but the results showed higher accuracy for men. It also thought that listeners from Area a would recognize lyrics better (H6), but the results showed that listeners from Area b performed better instead.

5.2 Tone-melody corresponding in Sichuan opera and listeners' perception

The analysis of the opera revealed that Sichuan opera exhibited a higher level of adherence to the compositional principle, with a compliance rate of 76.90%, surpassing those observed in Beijing opera (46.17%) and Suzhou Tanci (49%, Yang, 2019). This is a notable degree of compliance when compared to available data. The possible explanation for this could be the limited historical tonal variation in Sichuanese (Endo & Ishizaki, 2015). Furthermore, to avoid sacrificing musicality, it could be desirable to properly abandon strict adherence to the tonal-melodic correspondence (Wong & Diehl, 2002), so a slight deviation from the principle in Sichuan opera may be deemed acceptable. Hence, Sichuan opera may remain a suitable candidate for perceptual experimentation, though not reaching full conformity.

The result of the perception experiment revealed that listeners were significantly more accurate in recognizing 100% scale phrases than non-100% scale phrases, indicating that adherence to the compositional principle positively impacts listener recognition accuracy. As per the composition principle, the tone-melody mapping of traditional opera follows an incomplete ordinal mapping, except when the melody

moves downward when the tone remains the same, otherwise the ordinal mapping is strictly followed (Sun, 1983). Consequently, listeners may rely on the principle of ordinal mapping to identify lyrics, which is consistent with Wong and Diehl's (2002) assertion. Furthermore, the melodic downward movement in Sichuan opera is akin to the downdrift of tones in everyday conversation (Fromkin & Ohala, 2014). Given the listeners' familiarity with this phenomenon, the violation of the ordinal mapping in this situation may not affect listeners' recognition of the lyrics. Thus, listeners can utilize the tone-melody relationship specified by the composition principle to extract the lyrics.

The classification of participants in the perception experiment according to age revealed that individuals over 50 years old exhibited greater accuracy in recognizing Sichuan opera lyrics. This finding may be attributed to the fact that this age group constitutes the primary audience for Sichuan opera (Wang, 2023), and thus has greater exposure to and familiarity with Sichuan opera singing. This is consistent with Dowling et al. (2008) that the role of experience in music perception may be greater than the effect of age. Hence, although aging may lead to some degree of cognitive decline, experience can serve to compensate for this decline. Additionally, the observed difference in accuracy across age groups was more significant for phrases that fully adhered to the compositional principle, further substantiating the usefulness of this tone-melody mapping for lyric recognition.

Upon classifying the participants according to their native language, the finding indicated that native speakers exhibited higher accuracy rates. This result aligns with the assertion made by Dowling et al. (2001). Although this advantage was not significant when considering both 100% scale and non-100% scale phrases together, it became significant when focusing solely on phrases that fully adhered to the compositional principle. This outcome served to reinforce the importance of the tone-melody mapping relationship in facilitating lyric recognition.

The analysis of recognition accuracy by gender revealed incongruity with the hypothesis posited in this study. Specifically, the result indicated that males exhibited higher accuracy rates than females. Although this difference was not significant, it contradicted the assertion made by Miles et al. (2016) that females possess greater music recognition abilities. Additionally, the recognition advantage for males became significant in the 65+ age group, whereas Bleecker et al. (1988) suggested that the music perception advantage should be more prominent for females in the 66-89 age group. This finding may be attributed to more males in the audience for Sichuan opera

than females (Liu, 2018), which could result in greater experience and familiarity with Sichuan opera singing among males. This experience may serve as a compensatory factor that reduces the gap in musical perception abilities between males and females.

The result pertaining to the participants' accent areas also deviated from the hypothesis presented in the study. Specifically, the data indicated that listeners from Area b exhibited the highest accuracy rate, rather than Area a. This finding may be attributed to the fact that the northern part of Area b is also a popular region for Sichuan opera (Quan, 2019), which remains influential despite not being widely practiced. Additionally, Area b is the only one of the five accent areas that preserves the entering tone (Yang, 1984), resulting in the presence of five tones, one more than the other four areas. This difference may render participants from Area b more attuned to changes in pitch (Alexander et al., 2008), thereby enabling them to accurately identify the lyrics. Furthermore, Area a, the fastest urbanizing area in Sichuan, has the highest prevalence of Standard Mandarin (Sun, 2011). As a result, the Sichuan dialect spoken in Area a may be more influenced by Standard Mandarin. Consequently, the reason for the lower accuracy rates among participants from Area a may not solely attribute to vocal tones but could also be the consonants and vowels.

5.3 Limitations and suggestions for further study

The present study has several limitations that should be acknowledged. Firstly, the opera analysis only focused on Sichuan opera, and no other regional operas were included in the analysis, limiting the generalizability of the findings. Secondly, the number of participants in the perception experiment was small, which may have resulted in less accurate results. Lastly, the frequency interval setting was fixed at 16.7%, lending to no significant difference in the accuracy of recognition of scales below 83.3%.

To address these limitations, suggestions for further study are proposed. Firstly, future studies should expand the sample of operas analyzed to include other regional operas, which would provide greater insight into the generalizability of the findings. Secondly, recruitment efforts should aim to include participants with diverse backgrounds, and the number of participants in each classification should be roughly equal to increase the accuracy of results. Lastly, future studies should consider using a more precise frequency scale or adjusting the frequency interval setting to investigate

the impact of abandoning precise pitch changes in tonal language on communicative efficacy. These suggestions for further study could enhance the validity and generalizability of the findings and provide a more comprehensive understanding of the relationship between tone and melody in traditional Chinese music.

5.4 Implications

Despite these limitations, the study is informative as several implications can be drawn. Firstly, this research complements existing studies on tone-melody mappings in traditional opera and expands the sample of research on tone-melody mapping relationships. Besides, this study also identifies Sichuan opera as a suitable sample for perceptual experiments due to its greater adherence to the composition principle. Moreover, the study underscores the significance of adhering to the compositional principle in traditional opera and highlights the importance of preserving the tone-melody mapping relationship in facilitating the recognition of lyrics. The findings can inform the development of best practices for the composition and performance of traditional opera, providing useful insights for composers, performers, and educators in the field of traditional Chinese music.

6. Conclusion

In conclusion, this study investigated the tone-melody mappings in Sichuan opera lyrics and examined the relationship between adherence to the compositional principle and the accuracy of listeners' recognition. The results revealed that Sichuan opera exhibited greater adherence to the composition principle compared to other regional operas and that listeners' accuracy was positively influenced by adherence to the compositional principle. Moreover, the study also found that the accuracy of listeners' recognition was influenced by age, native language, gender, and accent areas. The study's limitations were also discussed, and suggestions for future research were offered. The implications of this study for traditional Chinese opera and music were also highlighted. Overall, this study provides valuable insights into the interplay between tone and melody in traditional Chinese music and underscores the importance of preserving the tone-melody mapping relationship in facilitating the recognition of lyrics.

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Appendixes

Appendix 1: Python for statistical tonal-melodic mapping relations

```
import csv
import numpy as np
import itertools

def deal_each_sentence(each_senten):
    each_word = each_senten.split(' ')
    # print('each_word:', each_word)
    each_word =list(map(int,each_word))
    # print('each_word:',each_word)
    # for each_pitch_inde in range(len(each_word[:-1])):
    #     cur_pitch = each_word[each_pitch_inde]
    #     next_pitch = each_word[each_pitch_inde + 1]
    #     if next_pitch > cur_pitch:
    #         up_donw_sentence_list.append(1)
    #     if next_pitch == cur_pitch:
    #         up_donw_sentence_list.append(0)
    #     if next_pitch < cur_pitch:
    #         up_donw_sentence_list.append(-1)
    return each_word


def deal_each_song(each_song):
    up_down_list = []

    song_list = each_song.replace('\n\n\n', '').replace('\n\n', '\n')
    sentence_list = song_list.split('\n')
    print('sentence_list:',sentence_list)
    sentence_list = list(map(deal_each_sentence, sentence_list))
    sentence_list = list(itertools.chain.from_iterable(sentence_list))
    for each_pitch_inde in range(len(sentence_list[:-1])):
        cur_pitch = sentence_list[each_pitch_inde]
        next_pitch = sentence_list[each_pitch_inde + 1]
        if next_pitch > cur_pitch:
            up_down_list.append(1)
        if next_pitch == cur_pitch:
            up_down_list.append(0)
        if next_pitch < cur_pitch:
            up_down_list.append(-1)

    return up_down_list
```

```
41.
42. def get_up_down(path):
43.     #   up: 1  down -1  same:0
44.     with open(path,encoding='utf-8') as f:
45.         each_list = f.read().strip().split('.')
46.         each_list = each_list[:-1]
47.         result = list(map(deal_each_song,each_list))
48.         list_all = list(itertools.chain.from_iterable(result))
49.         return list_all
50.
51.
52. if __name__ == '__main__':
53.     tone_path = './tone.txt'
54.     melody_path = './melody.txt'
55.     # tone_path = './tone_duizhao.txt'
56.     # melody_path = './melody_duizhao.txt'
57.
58.     print('tone')
59.     tone_up_down = get_up_down(tone_path)
60.     print('melody')
61.     melody_up_down = get_up_down(melody_path)
62.     print('tone:',tone_up_down)
63.
64.     print('melody:',melody_up_down)
65.
66.     up_tone = np.where(np.array(tone_up_down)==1,1,0)
67.     up_melody = np.where(np.array(melody_up_down) == 1, 1, 0)
68.
69.     down_tone = np.where(np.array(tone_up_down) == -1, 1, 0)
70.     down_melody = np.where(np.array(melody_up_down) == -1, 1, 0)
71.
72.     same_tone = np.where(np.array(tone_up_down) == 0, 1, 0)
73.     same_melody = np.where(np.array(melody_up_down) == 0, 1, 0)
74.
75.     up_up = np.sum(up_tone * up_melody)
76.     up_down = np.sum(up_tone * down_melody)
77.     up_same = np.sum(up_tone * same_melody)
78.
79.     down_up = np.sum(down_tone * up_melody)
80.     down_down = np.sum(down_tone * down_melody)
81.     down_same = np.sum(down_tone * same_melody)
82.
83.     same_up = np.sum(same_tone * up_melody)
84.     same_down = np.sum(same_tone * down_melody)
```

```
85.     same_same = np.sum(same_tone * same_melody)
86.
87.     mat_result = '{} {} {}\n{} {} {}\n{} {} {}'.format( up_up,  up_dow
    n,  up_same,
88.                                                 down_up,down_down,down_same,
89.                                                 same_up,same_down,same_same)
90.
91.     sum = up_up + up_down+up_same + down_up + down_down + dow
    n_same + same_up + same_down + same_same
92.
93.     print(mat_result)
94.     # print(up_up,down_down,same_down)
95.     print('sum:{},ratio:{}'.format(sum,(up_up+down_down+same_down
    )/sum))
```

Appendix 2: Python for statistical tonal-melodic mapping relations in each sentence

```
import csv
import numpy as np
import itertools
import matplotlib.pyplot as plt
def deal_each_sentence(each_senten):
    each_word = each_senten.split(' ')
    up_donw_sentence_list = []
    for each_pitch_inde in range(len(each_word[:-1])):
        cur_pitch = each_word[each_pitch_inde]
        next_pitch = each_word[each_pitch_inde + 1]
        if int(next_pitch) > int(cur_pitch):
            up_donw_sentence_list.append(1)
        if int(next_pitch) == int(cur_pitch):
            up_donw_sentence_list.append(0)
        if int(next_pitch) < int(cur_pitch):
            up_donw_sentence_list.append(-1)
    return up_donw_sentence_list
    print()

def deal_each_song(each_song):
    song_list = each_song.replace('\n\n\n', '').replace('\n\n', '\n')
    sentence_list = song_list.split('\n')
    return sentence_list

def comput_everysentence_ration(each_senten_up_down_tone,each_senten_up_down_melody):
    pass
def get_up_down(tone_path,melody_path):
    #  up: 1  down -1  same:0
    with open(tone_path,encoding='utf-8') as f:
        each_tone_list = f.read().strip().split('.')
        each_tone_list = each_tone_list[:-1]
        # each_tone_list2 = list(map(deal_each_song, each_tone_list))
    with open(melody_path, encoding='utf-8') as f:
        each_melody_list = f.read().strip().split('.')
        each_melody_list = each_melody_list[:-1]
    tone_allsentence_list = []
    melody_allsentence_list = []
    for each_song_index in range(len(each_tone_list)):

```

```
        each_song_tone = deal_each_song(each_tone_list[each_song_index])
        each_song_melody = deal_each_song(each_melody_list[each_song_index])
        tone_allsentence_list.extend(each_song_tone)
        melody_allsentence_list.extend(each_song_melody)

    tone_up_donw = list(map(deal_each_sentence,tone_allsentence_list))
    melody_up_donw = list(map(deal_each_sentence, melody_allsentence_list))
    result_ratio_list = []
    for each_up_donw_index in range(len(tone_up_donw)):
        each_sentence_updown_tone = tone_up_donw[each_up_donw_index]
        each_sentence_updown_melody = melody_up_donw[each_up_donw_index]
        up_tone = np.where(np.array(each_sentence_updown_tone) == 1, 1, 0)
        up_melody = np.where(np.array(each_sentence_updown_melody) == 1, 1, 0)

        down_tone = np.where(np.array(each_sentence_updown_tone) == -1, 1, 0)
        down_melody = np.where(np.array(each_sentence_updown_melody) == -1, 1, 0)

        same_tone = np.where(np.array(each_sentence_updown_tone) == 0, 1, 0)
        same_melody = np.where(np.array(each_sentence_updown_melody) == 0, 1, 0)

        up_up = np.sum(up_tone * up_melody)
        up_down = np.sum(up_tone * down_melody)
        up_same = np.sum(up_tone * same_melody)

        down_up = np.sum(down_tone * up_melody)
        down_down = np.sum(down_tone * down_melody)
        down_same = np.sum(down_tone * same_melody)

        same_up = np.sum(same_tone * up_melody)
        same_down = np.sum(same_tone * down_melody)
        same_same = np.sum(same_tone * same_melody)
```

```
71.         mat_result = '{} {} {}\n{} {} {}\n{} {} {}'.format(up_up, up_do
    wn, up_same,
72.                                                 down_up, down_down, down_sam
    e,
73.                                                 same_up, same_down, same_same
    )
74.
75.         sum = up_up + up_down + up_same + down_up + down_down +
    down_same + same_up + same_down + same_same
76.
77.         print(mat_result)
78.         ratio = (up_up + down_down + same_down) / sum
79.         print('sum:{},ratio:{}'.format(sum,ratio))
80.         result_ratio_list.append(ratio.round(2))
81.         print()
82.     return result_ratio_list
83.
84.
85. if __name__ == '__main__':
86.     tone_path = './tone.txt'
87.     melody_path = './melody.txt'
88.     # tone_path = './Lexical tone.docx'
89.     # melody_path = './Melody.docx'
90.
91.     result = get_up_down(tone_path,melody_path)
92.     set_result = sorted(set(result))
93.     result_dict = {}
94.
95.     for i in result:
96.         if i in result_dict.keys():
97.             result_dict[i] += 1
98.         else:
99.             result_dict[i] = 1
100.        print('result:', result_dict)
101.        for i in sorted(result_dict.keys()):
102.            print('{} : {}'.format(i,result_dict[i]))
```

Appendix 3: Questionnaire

香港教育大學
The Education University of Hong Kong

川剧的唱词声调研究

The realization of lexical tones in Sichuan opera

诚邀阁下参加李炯乐博士负责监督，卢珏羽负责执行的研究计划。他们分别是香港教育大学语言学及现代语言学系的教员和学生。

You are invited to participate in a project supervised by Dr. Albert Lee and conducted by LU JUEYU, who are a staff and a student of the Department of Linguistics and Modern Language Studies in The Education University of Hong Kong.

本研究旨在调查声调和旋律之间的顺序映射频率是否与听者正确识别歌词有关。我们希望邀请您参与这项研究，以便我们能够更了解川剧的声调-旋律关系。

This study aims to investigate whether the frequency of ordinal mapping between tone and melody is related to the correct identification of the lyrics by the listener. We would like to invite you to participate in this study so that we can better understand the tonal-melodic relationship of Sichuan opera.

这项研究没有潜在的风险。阁下的参与纯属自愿性质。阁下享有充分的权利在任何时候决定退出这项研究，更不会因此引致任何不良后果。凡有关阁下的数据将会保密，一切数据的编码只有研究人员得悉。

The study involves no potential risks. Your participation in the project is voluntary. You have every right to withdraw from the study at any time without negative consequences. All information related to you will remain confidential, and will be identifiable by codes known only to the researcher.

如阁下想获得更多有关这项研究的数据，请以电邮联系卢珏羽 或她的导师李炯乐博士

If you would like to obtain more information about this study, please contact LU JUEYU or her supervisor Dr. Albert Lee by email.

○ 我同意参加此项研究。I agree to participate in this study.

→

香港教育大學
The Education University of Hong Kong

一、语言背景调查 Part 1 Language background survey

1. 性别 Gender

- ○ 女 Female
- ○ 男 Male

2. 年龄 Age (e.g. 20)

3. 是否为四川话母语? Are you a native speaker of Sichuanese?

- ○ 是 Yes
- ○ 否 No

→

4. 口音片区 Accent area

- ○ 成渝片（成都、遂宁、重庆、巴中、广元、达州、资阳、广安等川东地区）
- ○ 西蜀片（都江堰、郫县等岷江流域地区）
- ○ 棉雅片（石棉、名山、雅安）
- ○ 仁富片（仁寿、自贡、内江）
- ○ 川西片（阿坝、木里等川西少数民族聚居地）

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4. 四川话使用年限 Year of using Sichuanese (e.g. 5)

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二、歌词感知实验 Part 2 Perceptual experiment

以下为感知实验注意事项，**请仔细阅读**：
Please read carefully the following notes on perception experiments.

在该部分，您将听到9段音频，每句歌词有**7个字**。在每段音频结束后，请您将听到的歌词**输入答题框**。
In this section, you will listen to 9 audio clips. Each sentence has **7 characters**. After listening, please **type** the lyrics you hear into the answer box.

这是一个感知实验，目的是收集您**对音调的感知**，因此您**不需要追求答案的正确率**，**凭借第一感觉写出您听到的字即可**（即使可能文意不通）。
This is a perception experiment to collect **your perception of tones**, so you **don't need to get the answers correct**, just **write the words you hear by first impression** (even if they may not make sense).

如有无法明确识别的字，请尽力找到**同音字**输入，或以**普通话拼音**代替（使用拼音请标出声调，例如；“一”的拼音输入为“yi1”，“学”的拼音输入为“xue2”）。
Unidentifiable and uncertain answers are acceptable, and please try your best to find **homophonic characters**, or use **Mandarin Pinyin** instead.

-0:08 请输入听到的歌词 Please enter the lyrics you hear

-0:05 请输入听到的歌词 Please enter the lyrics you hear

-0:06 请输入听到的歌词 Please enter the lyrics you hear

-0:07 请输入听到的歌词 Please enter the lyrics you hear

-0:03 请输入听到的歌词 Please enter the lyrics you hear

-0:05 请输入听到的歌词 Please enter the lyrics you hear

-0:08 请输入听到的歌词 Please enter the lyrics you hear

-0:03 请输入听到的歌词 Please enter the lyrics you hear

-0:05 请输入听到的歌词 Please enter the lyrics you hear

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香港教育大學
The Education University of Hong Kong

感谢您抽出宝贵的时间参加此调查。
已记录您的回复。

由 Qualtrics 提供支持