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Retroflex and non-retroflex laterals in the Zibo dialect of Chinese

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Abstract

This paper reports on an acoustic study of the retroflex lateral /ɭ/ and non-retroflex lateral /l/, as well as on the schwas following the two laterals in the Zibo dialect. Analyses of formants measured at the temporal midpoint of the lateral and schwa segments show that the retroflex lateral /ɭ/ has a significantly lower F1 as well as a significantly larger C/V duration ratio than the non-retroflex lateral. No significant difference is found in F2 or F3 of the two laterals. Moreover, the schwa following /ɭ/ has a significantly lower F1 than that following /l/, which could play a robust role of cue enhancement in distinguishing the preceding laterals, resulting in an overall enhancement of an otherwise auditorily vulnerable contrast in the laterals. Some inter-speaker variation is observed in the realization of /ɭ/, especially in F3, which may be indicative of a change in progress. These results provide insights into the phonemic status of the retroflex lateral in the Zibo dialect, which are further discussed in light of phonetic and phonological explanations.

Keywords: Zibo dialect; retroflex lateral; formant; C/V duration ratio; phonetic enhancement

1 Introduction

Laterals have been a topic of interest to linguists due to their complicated articulatory and acoustic features across languages, dialects and speakers. Although laterals are common, existing in about 82% of all the 317 sample languages in the UPSID (UCLA Phonological Segment Inventory Database), the retroflex lateral is rare and accounts for less than 7% of all laterals in this database. Comparatively, about 87% of all laterals are produced in the dental/alveolar region with probably more frequent alveolar laterals than dentals (Maddieson 1984). The comparative scarcity of the retroflex-dental/alveolar contrast for laterals has motivated research on data from different languages, for example the Dravidian languages of India and the indigenous languages of Australia. In this study, we examine the acoustic differences between the retroflex lateral /ɭ/ and non-retroflex alveolar lateral /l/ in the Zibo dialect of Chinese, contributing to the acoustic description of this typologically rare contrast from an underdescribed language.

Figure 1. Location of Zibo within China (left: map of China with Shandong province marked in red, downloaded from https://sacu.org/provmap.html#; right: map of Shandong province with Zibo City marked in orange, downloaded from https://zh.wikipedia.org/wiki/File:ChinaShandongZibo.png).

The Zibo dialect of Chinese is a member of the northern Mandarin Chinese family (ISO 693-3: [cmn]) spoken in Zibo, a city with an area of 5,965km^2 and a population of 4.70 million (China Discovery 2022) located in central Shandong province, People's Republic of China (see Figure 1). In classification, it belongs to Jilu Mandarin, one of the eight subgroups of the Mandarin family, together with Northeast, Beijing (Standard), Zhongyuan, Jiaoliao, Lanyin, Jianghuai, and Southwest (Wurm et al. 1987). Besides the rarity of the retroflex lateral and its underdocumentation in dialects of China, the retroflex lateral in the Zibo dialect is interesting for three main reasons. First, different acoustic findings are reported for the alveolar-retroflex contrast in laterals in studies of dialects in China and other languages in the world, especially for the F3 and duration of the two laterals. Second, the phonetic context of the retroflex lateral /ɭ/ in the Zibo dialect is different from that for the more studied Dravidian languages of India and the indigenous languages of Australia. Third, there is some controversy as to the phonemic contrast between the retroflex and non-retroflex alveolar laterals in the Zibo dialect. In the remainder of this section, we provide an introduction to previous phonetic studies of the retroflex and non-retroflex lateral contrast as well as an overview of Zibo phonology to further explain these three aspects.

1.1 *Acoustic and phonotactic characteristics of retroflex laterals in previous studies of other languages in the world*

Both the Dravidian languages of India and the indigenous languages of Australia are well known for having an alveolar versus retroflex contrast in the consonant system (Bhat 1973; Ladefoged & Maddieson 1996). Studies on retroflex laterals are reported for Dravidian languages spoken in South Asia (India, Pakistan and Sri Lanka), including Tamil (McDonough & Johnson 1997; Narayanan & Kaun 1999; Narayanan et al. 1999), Malayalam (Punnoose et al. 2013; Scobbie et al. 2013; Tabain & Kochetov 2018) and Kannada (Tabain & Kochetov 2018), and in Australian Aboriginal languages, such as Arrernte, Pitjantjatjara and Warlpiri (Tabain et al. 2016; Tabain et al. 2020a; Tabain et al. 2020b). Other fragmentary reports on retroflex laterals are found in Gujarati (Dave 1977) among the Indo-Aryan languages and in East Norwegian (Hamann 2003a; Moen et al. 2003) among the North Germanic languages. The retroflex lateral [ɭ] in East Norwegian does not have a phonemic contrast with

its non-retroflex counterpart, and it is a result of a retroflexion rule that merges /r/ and dento-alveolars across morpheme or word boundaries (Kristoffersen 2000).

Previous studies on this contrast in laterals have investigated articulatory and acoustic differences. Among Dravidian languages, Tamil is reported to have a dento-alveolar /l/ vs. retroflex lateral /ɭ/ contrast. When producing /ɭ/ in Tamil, the tongue is curled back so that contact with the palate is made with the underside of the tongue, and the narrowest tongue constriction appears in the palatal region (Narayanan et al. 1999). No consistent differences are found between /ɭ/ and /l/ in F1. A lower F3 is found in /ɭ/ than /l/, with a slightly higher F2 in /ɭ/ than /l/, and the duration of /ɭ/ is found to be considerably shorter than that of /l/ (McDonough & Johnson 1997; Narayanan et al. 1999). While the Tamil /ɭ/ has sublingual articulation with palatal constriction, /ɭ/ in Malayalam has a considerable tongue root retraction and a substantial tongue blade raising and retraction (Scobbie et al. 2013). Acoustic studies show a higher F1, lower F2 and lower F3 in /ɭ/ than in /l/ (Punnoose 2011; Punnoose et al. 2013; Tabain & Kochetov 2018). The lower F2 in /ɭ/ is the opposite to the finding for F2 in Tamil. The duration of /ɭ/ in Malayalam is also reported to be shorter than that of /l/ (Punnoose 2011; Tabain & Kochetov 2018), which is consistent with the finding of duration for Tamil. As for Kannada, descriptive phonetic accounts disagree on the exact place of the articulation of its non-retroflex coronal lateral /l/: some describe it as 'dental' (Bright 1958), others as 'alveolar' (Upadhyaya 1972), but they unanimously characterize /ɭ/ as retroflex, with some noting its subapical articulation. Tabain and Kochetov (2018) show in their acoustic investigation that Kannada retroflex /ɭ/ has a higher F1 and lower F3 than alveolar /l/, which is consistent with the findings for Malayalam. But different from Malayalam, Kannada retroflex /ɭ/ has a higher F2 than its alveolar counterpart /l/. Besides, echoing the findings for Tamil and Malayalam, the duration of the retroflex lateral in Kannada is found to be shorter than the alveolar lateral.

In some Central Australian languages, the alveolar and retroflex laterals are both apical (Tabain et al. 2020a). In an acoustic study of lateral consonants in three Central Australian languages: Arrernte, Pitjantjatjara and Warlpiri (Tabain et al. 2016), analyses of formants at the temporal midpoint of the laterals show that the retroflex /ɭ/ is not significantly different from the alveolar /l/ for F1 or F2, but there is a significantly lower F3 found in the retroflex lateral. No significant difference is found for duration of the two laterals.

Overall, discrepancies in formant patterns of the retroflex and non-retroflex (dental/alveolar) lateral contrasts reflect variations in realization in different languages, especially when producing retroflex laterals, caused by difference in place of contact of the tongue, degree of retraction of tongue tip/root, tongue tip flexion/raising, etc. Despite these variations, there is a consistently lower F3 for /ɭ/ than for /l/ in the Dravidian languages and the three Central Australian languages mentioned above, which suggests that F3 is a robust cue for the retroflex-dental/alveolar contrast in laterals. F3 is related to front cavity resonances (Fant 1970) and F3 in laterals can be at least partly suppressed by the lateral anti-resonance: some loss of energy resulting from a side-branch (a pocket of air above the tongue) (Kochetov, Petersen & Arsenault 2020). For retroflexes, Stevens (1998) finds a lower F3 during the constricted interval, due to a sublingual cavity. A lower F3 as a main correlate of retroflexes is also found in studies of vowels and other consonants (Ladefoged & Bhaskararao 1983; Ladefoged & Maddieson 1996; Hamann 2003b; Hussain et al. 2017).

Regarding the results for duration, the retroflex lateral /ɭ/ is reported to have a shorter duration than the non-retroflex /l/ in Tamil, Malayalam and Kannada. In the three Australian Aboriginal languages (Tabain et al. 2016), there is no significant difference in duration between the two apical laterals /ɭ/ and /l/, with both having shorter durations than the laminal laterals.

In addition to the articulatory and acoustic characteristics of the retroflex and non-retroflex lateral contrast, the phonotactics of /ɭ/ and /l/ are also discussed in previous

studies. Findings show that retroflex laterals occur at different positions in a word in different languages. In Tamil, both /l/ and /ɭ/ occur in intervocalic and word-final positions, but the phonotactics of Tamil bar retroflex sounds from initial position (McDonough & Johnson 1997), and Narayanan et al. (1999) has also noted that /ɭ/ in syllable-initial cases in Tamil is realized as a flap, and often may not involve complete (subapical) palatal contact in fluent speech, different from a complete linguapalatal closure for /ɭ/ in the syllable-final position. This may also explain the shorter duration of the retroflex lateral /ɭ/ than its dental/alveolar counterpart /l/ in Tamil. Similarly, in Kannada, both /l/ and /ɭ/ occur frequently intervocalically, /l/ also occurs word-initially but neither lateral occurs word-finally (Tabain & Kochetov 2018). Laterals /l/ and /ɭ/ in Malayalam occur in a wider range of contexts, contrasting word-medially, word-finally, and rather infrequently, word-initially (Tabain & Kochetov 2018). For the three Central Australian languages – Arrernte, Pitjantjatjara and Warlpiri, the contrast between the alveolar and the retroflex also mainly occurs intervocalically and is neutralized in the word-initial position (Tabain et al. 2016; Tabain & Beare 2018; Tabain et al. 2020a). It can be seen that the retroflex lateral /ɭ/ in the languages mentioned above most frequently occurs intervocalically, less often in the word-final position, and is rare in the word-initial position. This tendency is found to be common in previous studies and it is also noted that retroflex consonants in CV structure are not as well distinguished as in VC structure (Steriade 1995; Ohala & Ohala 2001; Hamann 2003b; Tabain et al. 2020a). In addition, the retroflex-alveolar contrast is found to be most clearly realized in the context of an /a/ vowel, and least clearly realized in the context of an /i/ vowel (Tabain et al. 2020a).

The literature also shows that inter-speaker variation of laterals is high, especially of the retroflex lateral (Stevens 1998; Nance 2014; Kochetov et al. 2020; Tabain et al. 2020a), due to individual speaker differences, language change, modes of acquisition in revitalization contexts, positional and contextual factors and task effects, etc.

In summary, the research review on the retroflex lateral and its dental/alveolar contrasts shows that there are different realizations of the retroflex lateral /ɭ/ in different languages, but some characteristics of this phoneme are shared by most of the languages mentioned above: a lower F3 and shorter duration than its dental or alveolar counterpart /l/, its infrequent occurrence (even barred or neutralized in some languages above) in the word-initial position as well as a large variation of its realizations.

1.2 *Acoustic and phonotactic characteristics of retroflex laterals in previous studies of dialects of Chinese*

The retroflex lateral is also reported in dialects of Chinese. A syllabic retroflex lateral is found in Susong Gan dialect of Anhui province in Northeast China (Tang 2005) and in Jincheng dialect of Shanxi province in North China (Zhu & Jiao 2006). [ɭ] in Susong Gan dialect is non-phonemic as a variant of the alveolar lateral /l/, and in Jincheng dialect, /ɭ/ is a phonemic syllabic consonant. In addition, the retroflex lateral is recorded as a phoneme in records of dialects in some areas of Shandong province (see Figure 1), for example in Zibo, Lijin, Qingdao, Linyi and Heze (Meng & Luo 1994; Yang 1990; Qingdao Municipal Archive 1997; Ma & Wu 2003; Qi 2019). In these dialects, the retroflex lateral is recorded to only occur syllable-initially, followed by a shorter and higher schwa to form the syllable /ɭə/.

Compared with studies of retroflex laterals in other languages of the world, studies and records on retroflex laterals in Chinese dialects are few and mainly just report the existence of this phoneme without detailed articulatory or acoustic analyses. To the best of our knowledge, there are three acoustic studies of /ɭ/ in dialects of Chinese, one on the syllabic retroflex phoneme /ɭ/ in Jincheng dialect with one female speaker (Zhu & Jiao 2006), the

second on the retroflex consonant /ɭ/ in the dialects of some areas from Heze and Linyi in Shandong province with one to two male speakers for each area (Qi 2019) and the third is a case study by Dong and Liang (2019) with one 61-year-old female speaker in the Zibo dialect. For the first two studies, only descriptive data analyses are given without statistical data analyses. It is found that the syllabic /ɭ/ in Jincheng dialect has a lower mean F1 and higher mean F2 than its alveolar counterpart /l/, but no difference is found in F3 of the two laterals. The acoustic analysis of the phonemic consonant /ɭ/ by Qi (2019) finds no difference in F1 for the two laterals, but for data from most areas in the research, F2 for /ɭ/ is lower than that for /l/; as for F3, the study does not find a consistently lower F3 in /ɭ/ than /l/ through F3 trajectory observation. Regarding the duration of the laterals, Qi (2019) reports that the retroflex lateral /ɭ/ has a longer duration than the alveolar /l/, with an average of 127 ms for /ɭ/ and 52 ms for /l/. The case study on /ɭ/ and /l/ in the Zibo dialect has investigated the acoustic characteristics of the two laterals and the schwas following them (Dong & Liang 2019). In this study, the retroflex lateral /ɭ/ in the Zibo dialect is found to have a significantly lower F1 and a significantly higher F2 than /l/; the duration of /ɭ/ is significantly longer than that of /l/ with a large difference. No significant difference is found in F3 of the two laterals. In addition, the schwa following /ɭ/ has a significantly lower F1 and shorter duration than the schwa following /l/.

It can be seen that a consistent lower F3, the main correlate for a retroflex lateral compared with its dental/alveolar counterpart in other languages, is not found in the few acoustic studies on the retroflex lateral in dialects of Chinese. The duration of /ɭ/ is longer than /l/ in dialects of Zibo, Heze and Linyi (Dong & Liang 2019; Qi 2019), which is the opposite to findings of Tamil, Malayalam and Kannada and different from the three Australian Aboriginal languages (McDonough & Johnson 1997; Narayanan et al. 1999; Punnoose 2011; Tabain et al. 2016; Tabain & Kochetov 2018). As for the phonetic context, in the Zibo dialect, /ɭ/ occurs in a restricted phonetic environment: only in the syllable-initial position followed by schwa, which is considered an infrequent or even barred position for /ɭ/ in other languages.

1.3 Zibo phonology and its lateral contrasts

The Zibo dialect differs in a number of important ways from the best-known Mandarin variety (i.e., the Standard Mandarin) not only in its tonal system but also in several segmental properties. The Zibo dialect has three lexical tones, marked here with the numerical superscripts 1–3 representing three tonal categories. Using the tone characters of Chao (1930) recommended in the International Phonetic Alphabet (IPA), we can transcribe the tones as T1 (˦˩), T2 (˥) and T3 (˩). Phonetically, the pitch height is represented by numbers from 1 (lowest) to 5 (highest). Marked examples of the citation forms of three tones in the Zibo dialect are presented in Table 1. Besides the full lexical tones, many Mandarin dialects have a neutral tone, commonly known as T0. Neutral-tone syllables are generally short and prosodically weak, and they receive tone values from the preceding full-tone syllable (Chen & Gussenhoven 2015). In this study, the neutral tone in the Zibo dialect is marked as T0.

The Zibo dialect has 24 phonemic consonants, as shown in Table 2. All consonants only occur syllable-initially, except /ŋ/ which can occur in both syllable-initial and syllable-final positions (e.g., /ŋɛ¹/ 'sad' vs. /ləŋ¹/ 'to throw'). The vowel inventory (including monophthongs, diphthongs and triphthongs) is also shown in Table 2. There are seven monophthongs in the Zibo dialect /i y u ə ɑ ɛ ɔ/, all of which can appear in open syllables. Only five of them (/i y u ə ɑ/) can appear in closed syllables with a nasal coda /ŋ/.

The syllable structure in the Zibo dialect is (C)V(/ŋ/), where C stands for consonant and V for vowel. The obligatory element V can be a monophthong, a diphthong or a triphthong.

Table 1. Citation tones in the Zibo dialect (based on Meng & Luo 1994)

	Tone in Chao tone letters	Tone numbers	Phonetic	Gloss
Tone 1	⌐⌐⌐ (mid to low to mid dipping)	214	pa^1	'eight'
Tone 2	⌐ (high level)	55	pa^2	'to pull out'
Tone 3	√ (mid to low falling)	31	pa^3	'father'

Table 2. Consonant (a) and vowel (b) inventories in the Zibo dialect (based on Meng & Luo, 1994)

(a)	Bilabial		Labio-dental		Alveolar		Post-alveolar	Retroflex		Palatal	Velar	
	vl	vd	vl	vd	vl	vd	vd	vl	vd	vl	vl	vd
Plosive	p pʰ				t tʰ						k kʰ	
Affricate					ts tsʰ			tʂ tʂʰ		tɕ tɕʰ		
Nasal		m				n	ɳ					ŋ
Fricative			f	v	s			ʂ		ɕ	x	
Lateral Approximant					l			ɭ				

(b)	Open syllable	Closed syllable before coda /ŋ/
Monophthongs	i, y, u, ə, ɑ, ɛ, ɔ	ɑŋ, əŋ, iŋ, uŋ, yŋ
Diphthongs	iɑ, uɑ, iə, uə, yə, iɛ, uɛ, ei, iɔ, əu	iɑŋ, uɑŋ
Triphthongs	uei, iəu	
Nasalized	ã, ɔ̃, iã, uã, yã, iɔ̃, uɔ̃, yɔ̃	

Note: vl is short for 'voiceless' and vd for 'voiced.'

The following examples show the possible syllable structures in the Zibo dialect: /i¹/ 'clothes', /iŋ²/ 'success', /li²/ 'pear', /liŋ²/ 'bell' and /liɑŋ²/ 'food', with superscript numbers denoting the tone category of the monosyllabic words, see Table 1.

Like many varieties in the Mandarin family, the Zibo dialect shows a two-way (alveolar and retroflex) coronal contrast in fricatives /s, ʂ/ (e.g., /sɑ¹/ 'to let go' vs. /ʂɑ¹/'sand') and affricates /ts, tʂ, tsʰ, tʂʰ/ (e.g., /tsɑ²/ 'complex' vs. /tʂɑ²/ 'to fry', and /tsʰɑ¹/ 'to rub' vs. /tʂʰɑ¹/ 'to insert'). Of particular interest is the alveolar-retroflex contrast in laterals. In the Zibo dialect, the alveolar lateral /l/ can be followed by most vowels (including nasalized vowels), while the retroflex lateral /ɭ/ can only be followed by the mid-vowel /ə/. In this context, minimal pairs of monosyllabic words show the phonemic contrast of the two laterals: /lə²/ 'to bother' vs /ɭə²/ 'son', /lə³/ 'heat' vs /ɭə³/ 'two' (see more examples in Tables A1 and A2 in Appendix A). The diachronic development of the retroflex lateral in Mandarin dialects is considered to be related to the development of a retroflex high vowel after an initial retroflex affricate (Zhang 1999; Gao 2013). In some dialects of Shandong province where Zibo is located, this combination is pronounced as a retroflex vowel /ɚ/, as in Standard Mandarin (Lee & Zee 2003) and most northern dialects in China, while in some other dialects of Shandong, it is pronounced as /ɭə/, such as in dialects of Zibo, Linyi and Zhucheng (Qian, Zhang & Luo 2001).

Another point of interest presented by Zibo laterals involves their somewhat contradictory descriptions in the literature. It is noted that the schwa following the retroflex lateral /ɭ/ in the Zibo dialect is recorded to be higher than that following the alveolar lateral /l/, which is also confirmed by finding a lower F1 in the schwa following the retroflex lateral /ɭ/ in Dong and Liang (2019). Regarding the more obvious difference between the two schwas following /ɭ/ and /l/ in auditory impression, Zhang (1999) suggests an /ɨ/ phoneme to denote the higher schwa following the retroflex lateral and considers that the two laterals belong to the same /l/ phoneme since the difference in auditory impression between the two laterals is minor (Zhang 1999; Qi 2019). This is inconsistent with Meng and Luo (1994)'s records of the Zibo dialect, which report an alveolar-retroflex phonemic contrast of the two laterals in the Zibo dialect.

All the discrepancies found in the acoustic and phonotactic characteristics of the two laterals in the Zibo dialect compared with other languages or dialects, together with the controversy as to the phonemic status of the retroflex lateral and its following schwa, need further exploration and explanation.

1.4 Domain and aim of the present paper

In all varieties and dialects of Chinese, most morphemes are exactly one syllable long (Wang 1973). In addition, most morphemes are also monosyllabic words in Chinese and it is fair to say that most Chinese syllables are monosyllabic words; there are also polysyllabic words, usually compounds (Duanmu 2011). Therefore, in the Zibo dialect, the syllable-initial position of /ɭ/ and /l/ is also the word-initial position of the monosyllabic words /ɭə/ and /lə/.

This study focuses on the acoustic analyses of the differences between the retroflex lateral /ɭ/ and the alveolar lateral /l/, as well as the two schwas following the two laterals in the Zibo dialect. The minimal pair /ɭə/ and /lə/ (monosyllabic words) will be studied. The research questions are as follows:

(1) What are the acoustic differences between /ɭ/ and /l/ in the Zibo dialect?
(2) What are the acoustic differences between the schwas following the two laterals?
(3) What is the phonemic status of the two laterals and the schwas following them?

2 Methods

2.1 Speakers

This study presents data from 22 native speakers of the Zibo dialect in two gender groups: 11 male speakers (five of them aged between 55–70, and six of them aged between 30–45) and 11 female speakers (six of them aged between 55–70, and five of them aged between 30–45). These speakers were chosen because all of them had lived and worked in Zibo ever since they were born. None of them were teachers or in a profession where Standard Mandarin was needed during work. All subjects speak the Zibo dialect in their daily communication, with very few chances of speaking Standard Mandarin. Among these speakers, those aged over 55 can speak the Zibo dialect and very little Standard Mandarin, and most younger speakers (aged 30–45) can speak both the Zibo dialect and Standard Mandarin.

2.2 Materials and procedure

The wordlist for this study contained 80 compound words with two syllable-initial laterals in the Zibo dialect, namely 40 words for /ɭə/ and 40 words for /lə/. The 80 words were

Table 3. Sample compound words in the wordlist

	Target	Phonemic	Orthography	Gloss
lɚ	lɚ²	lɚ² ny²	儿女	'son and daughter'
		lɚ² pɑ⁰	耳巴	'slap on the face'
	lɚ³	lɚ³ ʂɻ̩²	二十	'twenty'
		lɚ³ tʂʰɑŋ²	日常	'daily'
lə	lə²	lə² ʂei³	惹事	'to make trouble'
		lə² xuɚ² ʂɔ¹ ʂə̃¹	惹火烧身	'to bring trouble upon oneself'
	lə³	lə³ tɕʰiŋ²	热情	'passion'
		lə³ tɕʰɻ̩³	热气	'hot air'

carefully chosen from the records of the Zibo dialect (Meng & Luo 1994) and words native speakers were familiar with. Before the recording, the wordlist was checked by three native speakers to make sure words on the list were frequently used in their lives.

All 80 compound words in the wordlist were read by each of the 22 subjects in random order in the carrier sentence /vǝ¹ tu²_____ tǝ⁰ ___ sã¹ piæ̃³/. Since the English translation does not reflect the Chinese word order in the carrier sentence, here is an example of a complete morpheme-by-morpheme gloss as well as the translation of the carrier sentence for ease of readers' understanding: /vǝ¹ tu² lɚ²suɚ̃¹ tǝ⁰ lɚ² sã¹ piæ̃³/ 'I read /lɚ²suɚ̃¹/ ('son and grandson') of /lɚ²/ ('son') three times', translated as 'I read /lɚ²/ as in /lɚ²suɚ̃¹/ three times'. Then the 80 sentences were read a second time in the same order. The carrier sentence is designed to help speakers produce more natural pronunciations (Müller 2015) with a sentence focus on the monosyllabic word /lɚ/ or /lə/ (the second /lɚ/ or /lə/ in the carrier sentence, shown in bold in the example above). Laterals and schwas of the monosyllabic word /lɚ/ or /lə/ in the carrier sentence were extracted as target tokens. The recording from the second time was used for analysis because speakers were more practiced and relaxed when doing the second recording, which was more fluent and natural with fewer mistakes due to nervousness.

The recordings were made onto a laptop computer by the first author (a native of Zibo) in 2019 in a local sound-proof recording booth, using a Sennheiser GSP 602 headset microphone at a sampling rate of 44.1kHz. Some of the words in the recording are provided in Table 3 as examples and the whole wordlists are attached in Tables A1 and A2 in Appendix A. (Note: the target tokens extracted for analysis are not from the compounds in the wordlist, but from the monosyllabic /lɚ/ and /lə/ in the focus position of the carrier sentence).

In order to have a detailed understanding of the two schwas regarding their positions in the vowel chart, we also recorded monosyllabic words with the alveolar lateral /l/ followed by other monophthongs in the Zibo dialect, i.e., /li, ly, lu, lɑ, lɛ, lɔ/ by the same 22 speakers after the recording of /lɚ/ and /lə/ in the recording procedure. The same carrier sentence was used in the recording, and for each vowel of /i, y, u, ɑ, ɛ, ɔ/, 30 tokens from 30 monosyllabic words were extracted.

2.3 Annotation and analyses

Annotation and acoustic analysis were performed using Praat (Boersma & Weenink 2021). All tokens were manually annotated based on auditory impression, the waveform and spectrogram of the target sounds. The boundaries of laterals were mainly determined by a
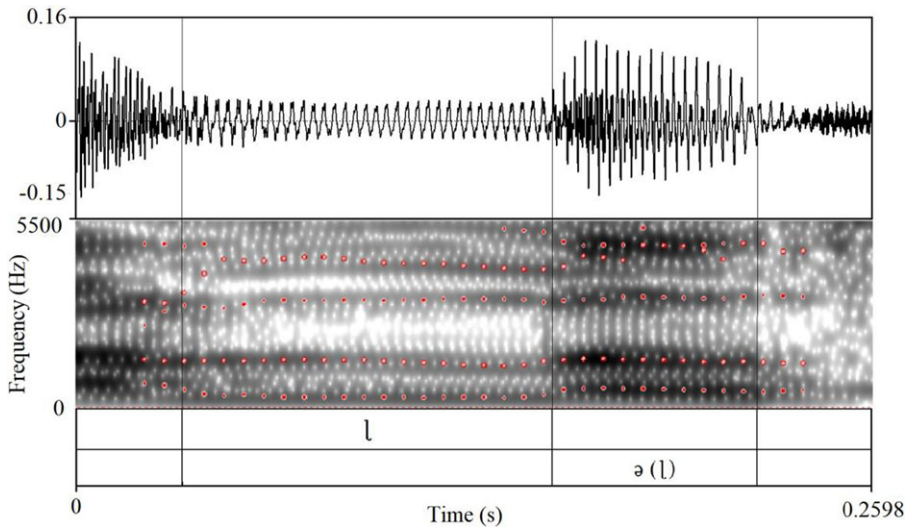
Figure 2. Sample Praat annotation for /ɭə/.

relatively low overall amplitude and weaker formant structure (lighter in the spectrogram), and lower F1 with respect to adjacent schwas (cf. Machač & Skarnitzl 2009; Kochetov et al. 2020). The following schwas were annotated based on the onset and offset of a similar periodic waveform and inspections of the end of regular glottal pulses with stable vowel formants in the spectrogram. Figure 2 presents a sample annotated token /ɭə/ in Tone 3 by one of the female speakers.

Running a Praat script (with LPC Burg method), formants and duration information for each segment were extracted. The first three formant values in Hz were extracted at 11 evenly distributed points during each lateral and each vowel with the default window settings (a 25 ms Gaussian window with a 5 ms step). The maximum formant value used in the Burg analysis was set by gender (5000 Hz for males and 5500 Hz for females) to find five formants. Data for the temporal midpoint (point 6) of each segment were used for the static analysis of the laterals and schwas (Tabain et al. 2016; Tabain & Kochetov 2018; Kochetov et al. 2020). Since the presence of antiformants and lower spectral intensities can affect the accuracy of automatic formant tracking in lateral approximants (Punnoose et al. 2013; Kochetov et al. 2020), we performed a manual re-check of all lateral tokens through an inspection of spectrograms and FFT spectra in order to correct for potential errors (cf. Johnson 2012; Punnoose et al. 2013; Kochetov et al. 2020). Altogether 3520 target tokens from the monosyllabic words /ɭə/ and /lə/ (including 880 /ɭ/, 880 /l/, 880 [əɭ] and 880 [əl]) were extracted. In addition, 660 tokens for monophthongs /i, y, u, ɑ, ɛ or ɔ/ following /l/ (30 tokens from each of the 22 speakers) were extracted, and the F1 and F2 values at their temporal midpoints were measured in Praat to calculate the mean F1 and F2 for each vowel, shown in the vowel chart of the Zibo dialect in Figure 3. In order to maintain the consistency of auditory and acoustic analyses, laterals produced as syllabic consonants were removed from data analysis.

Two analyses were conducted on the laterals and the following schwas: a static acoustic analysis and a dynamic acoustic analysis. For the descriptive part of the static analysis, F1, F2 and F3 values (Hz) of laterals and schwas in two gender groups as well as the duration of each segment were presented in order to facilitate comparisons with studies of other

languages and dialects. The measures used for the statistical analyses to capture the spectral differences between the two laterals and between the two schwas were F1, F2 and F3 in Bark (Traunmüller 1990). In order to normalize the speech rate of different speakers (Miller 1981; Port & Dalby 1982), C/V duration ratio (DR: the duration of lateral divided by the duration of schwa) was used in the statistical analyses to reflect the temporal information of the lateral in relation to that of the following schwa in the monosyllabic words.

2.4 Statistics

Linear Mixed Effects (LME) models were constructed to the overall dataset to examine each formant measure (F1, F2 and F3 in Bark) at the temporal midpoints (point 6) of the two laterals and the schwas following them, as well as the C/V duration ratio of the two laterals in the monosyllabic words, with the *lmer*() function in the *lme4* package (Bates et al. 2015) in R (version 4.1.1; R Core Team 2021). The models were:

FiL ~ Consonant + (Consonant|Speaker) + (1|Item), where FiL = Lateral F1, F2, F3 (Bark)
DR~ Consonant + (Consonant|Speaker) + (1|Item), where DR = Lateral Duration Ratio
FiV ~ Vowel + (Vowel|Speaker) + (1|Item), where FiV = Vowel F1, F2, F3 (Bark)

The fixed factor was 'Consonant' (/ɭ/, /l/) or 'Vowel' (/ə/ following /ɭ/, /ə/ following /l/) in the models. 'Speaker' and 'Item' were the random factors. Tests were conducted separately for each formant measure for both the laterals and the following schwas, as well as for the C/V duration ratio of laterals. In addition, a paired sample t-test was conducted on the two laterals and the two schwas for each speaker to see individual variation with significance.

Dynamic formant analyses were conducted in order to present a clearer picture of the differences between the two laterals and between the schwas following them across the whole syllable interval. It was done by time-normalizing each segment with 11 points, with altogether 21 points for each syllable /ɭə/ or /lə/ since the eleventh point of the consonant segment overlapped the first point of the following vowel. We used 11 time-normalized points for each segment in the CV syllable rather than 21 time-normalized points across the entire CV interval as in Nance (2014), because there was difference in the duration of the two laterals and the schwas following them, as shown in the static data analysis. We wanted to capture equivalent points for each phoneme for comparison. Formant trajectories were analyzed using Smoothing Spline ANOVAs and 95% Bayesian confidence intervals and further visualized in R, similar to Nance (2014) and Kirkham (2017), also see Davidson (2006) for a general discussion of SS-ANOVA as related to speech research.

3 Results

The static and dynamic acoustic analysis are presented separately in the following sections. [ə̍ɭ] and [ə̍l] are used to distinguish the schwas following /ɭ/ and /l/ for ease of readability. [ə̍ɭ] with a subscript retroflex lateral denotes the schwa following /ɭ/ and [ə̍l] with a subscript alveolar lateral for that following /l/.

3.1 Results of the static acoustic analysis

3.1.1 Formant frequencies of laterals and schwas as well as the C/V duration ratio of laterals
A general description of the values in Hz of the first three formants as well as the duration information (means and SDs) of the laterals and the following schwas in the two gender

Table 4. Formant frequencies (Hz) and duration (ms) information for laterals (a) and schwas (b) at the temporal midpoint (mean with SD in bracket)

(a)	Lateral	F1	F2	F3	Duration	Duration ratio
Male	/ɭ/	328 (39)	1421 (96)	2556 (156)	142 (27)	2.57 (0.93)
	/l/	352 (44)	1409 (109)	2587 (146)	109 (25)	1.51 (0.53)
Female	/ɭ/	371 (41)	1647 (137)	2991 (191)	162 (31)	2.48 (0.87)
	/l/	394 (47)	1646 (124)	3023 (196)	122 (28)	1.36 (0.38)

(b)	Schwa	F1	F2	F3	Duration	Duration ratio*
Male	[əɭ]	517 (53)	1359 (97)	2583 (185)	63 (26)	0.45 (0.18)
	[əl]	646 (54)	1304 (81)	2547 (167)	78 (25)	0.74 (0.24)
Female	[əɭ]	661 (57)	1560 (92)	3009 (189)	73 (23)	0.46 (0.15)
	[əl]	840 (50)	1556 (87)	2933 (258)	96 (27)	0.81 (0.23)

Note: Duration ratio* here refers to the duration of schwa divided by the duration of lateral in the monosyllabic word.

groups are tabulated in Table 4, facilitating comparisons with studies of other languages and dialects.

It can be seen in Table 4 that for both groups, mean F1 of the retroflex lateral is lower than that of the alveolar lateral. No obvious difference is found for F2 between /ɭ/ and /l/ in either gender group. The retroflex lateral does not show an obvious lower F3 value (a mean of 31Hz lower for the male group and a mean of 32Hz lower for the female group) compared with its non-retroflex counterpart as it does in other languages, for example, a mean of 230Hz lower for Malayalam males (Tabain & Kochetov 2018), and a mean of 600 Hz lower for a Tamil male (Narayanan et al. 1999). Additionally, the mean duration of /ɭ/ in the Zibo dialect in both groups is longer than /l/ in monosyllabic words.

As for [əɭ] and [əl], the major difference is found in their F1 values and durations, with [əɭ] having an average lower F1 and shorter duration than [əl] in both groups. In addition, similar to the finding of Standard Mandarin (Mok 2009), the Zibo dialect also has a syllable-timed rhythm, therefore, the shorter duration of [əɭ] could be predicted by the longer duration of /ɭ/ in the monosyllabic word and the same is true for [əl]. These results imply that although both are marked /ə/ in the records of the Zibo dialect (Meng & Luo 1994), there are acoustic differences between the two schwas. Figure 3 shows the data for the monophthongs in the Zibo dialect. In the vowel charts of both gender groups, [əl] is below the central part on the vertical axis (F1), and [əɭ] occurs around the central part of the vowel chart; in both groups, [əɭ] and [əl] have very similar F2 values and [əɭ] has a lower F1 than [əl].

Formant frequencies were then converted to Bark scale for the statistical analyses. Significant results from the LME models are presented in Table 5 with the alveolar lateral /l/ and its following schwa [əl] set as the baseline. Boxplots comparing F1, F2 and F3 as well as the C/V duration ratio of the two laterals are presented in Figure 4.

The LME results in Table 5 show that the retroflex lateral /ɭ/ has a significantly lower F1 than the alveolar retroflex /l/ ($\beta = -0.23$, SE = 0.03, $t = -6.54$, $p < .0001$). No significant difference is found for F2 ($\beta = 0.03$, SE = 0.04, $t = 0.85$, $p = .4070$) or F3 ($\beta = -0.07$,
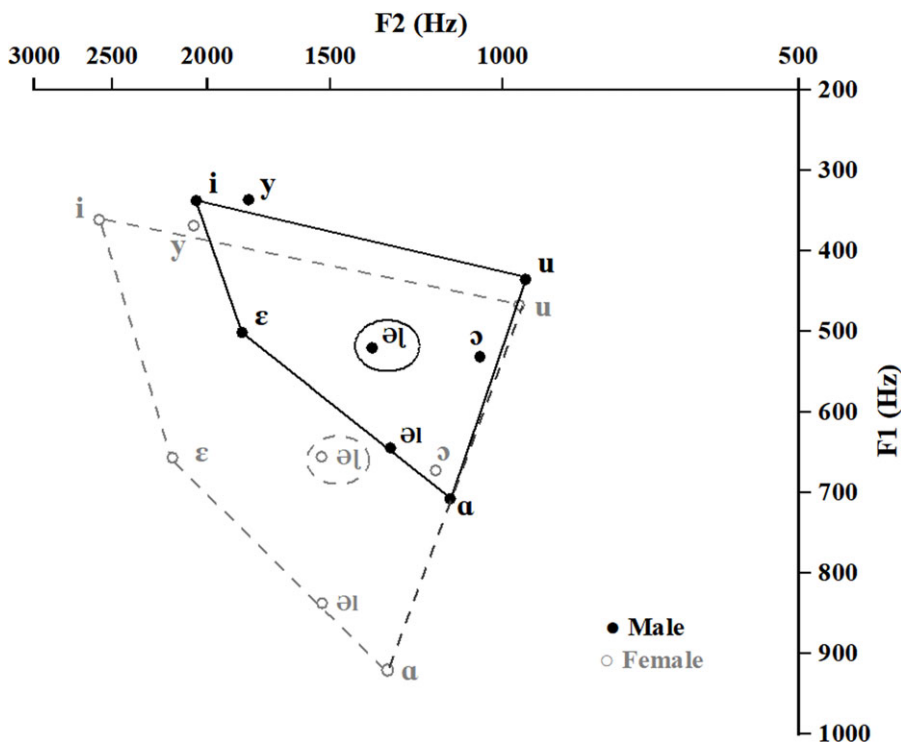
Figure 3. Vowel chart of monophthongs in the Zibo dialect based on F1 and F2 means (Hz) at vowel temporal midpoint, N = 660 for /i, y, u, ɑ, ɛ or ɔ/ and N = 880 for [əⱡ] and [əl] (Black solid line: the male group; gray dashed line: the female group).

SE = 0.04, $t = -1.86$, $p = .0775$) of the two laterals. As for the C/V duration ratio of laterals (DR), it is found that /ⱡ/ has a significantly higher duration ratio than /l/ ($\beta = 1.08$, SE = 0.11, $t = 10.19$, $p < .0001$). These results suggest that the major acoustic differences between the two laterals in the Zibo dialect are a significantly lower F1 and a significantly larger duration ratio of the lateral for the retroflex lateral, see the boxplots comparing formants and duration ratio of the two laterals in Figure 4.

Generally, a lower F1 is usually an acoustic correlate of raised tongue body, higher tongue body position or an anterior occlusion like round lips or raised tongue tip (Stevens 1998; Johnson 2012). The significantly lower F1 found in the retroflex lateral could be an intrinsic property of the sound, but it should be noted that the schwa following /ⱡ/, namely [əⱡ] in the present study, is recorded to be higher than schwas following other consonants in the Zibo dialect (Meng & Luo 1994). If we take coarticulation into consideration, the lower F1 in retroflex laterals could also be caused by the lower F1 in its following schwa. This will be further discussed in the dynamic analysis in Section 3.2.

The result for F2 of the two laterals is different from the previous case study in Dong and Liang (2019) where a higher F2 was found in /l/ in the data of a native female speaker, which might be due to individual variability in articulation. The result for F3 for the two laterals is consistent with previous studies of some Chinese dialects (Zhu & Jiao 2006; Dong & Liang 2019; Qi 2019), but different from the findings for studies of /l/ in other languages, such as Tamil (McDonough & Johnson 1997; Narayanan et al. 1999), Malayalam (Punnoose 2011; Punnoose et al. 2013; Tabain & Kochetov 2018), Gujarati (Dave 1977), Kannada (Tabain &

Table 5. LME results for the formant data at midpoints of laterals and schwas, and the duration ratio of laterals, with /l/ as the baseline for the laterals and [əₗ] for the following schwas

		Effect	β	SE	t	p
Lateral	F1	Intercept	3.75	0.08	47.53	<.0001 ***
		Retroflex lateral /ɭ/	−0.23	0.03	−6.54	<.0001 ***
	F2	Intercept	11.18	0.15	73.80	<.0001 ***
		Retroflex lateral /ɭ/	0.03	0.04	0.85	= 0.4070
	F3	Intercept	15.21	0.13	114.21	<.0001 ***
		Retroflex lateral /ɭ/	−0.07	0.04	−1.86	= .0775
	DR	Intercept	1.45	0.09	16.78	<.0001 ***
		Retroflex lateral /ɭ/	1.08	0.11	10.19	<.0001 ***
Schwa	F1	Intercept	6.80	0.17	40.85	<.0001 ***
		Schwa following /ɭ/	−1.18	0.05	−23.70	<.0001 ***
	F2	Intercept	10.75	0.15	74.13	<.0001 ***
		Schwa following /ɭ/	0.11	0.07	1.64	= .1170
	F3	Intercept	15.06	0.14	107.10	<.0001 ***
		Schwa following /ɭ/	0.14	0.06	2.42	= .0246 *

Note: DR is the abbreviation of C/V duration ratio.
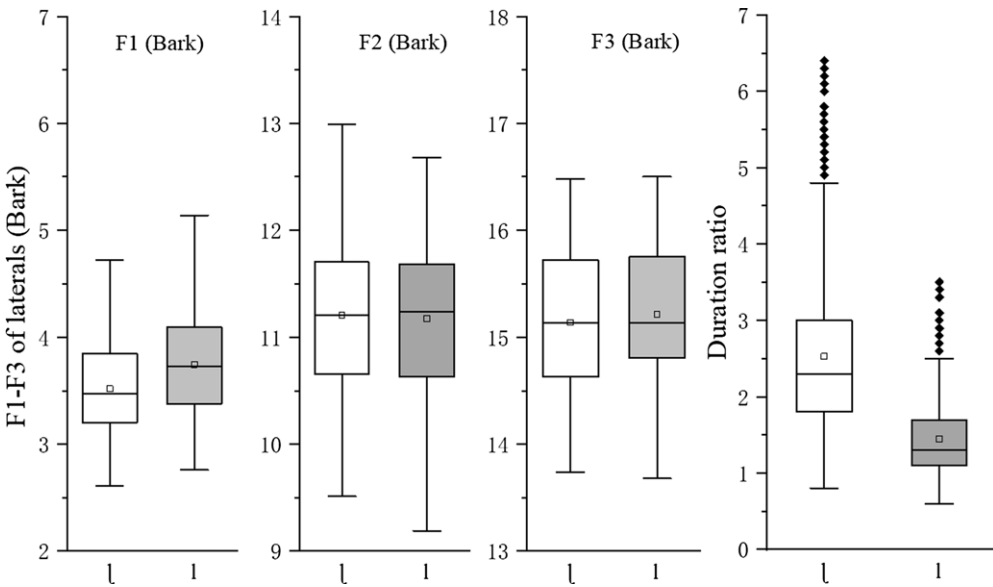
Figure 4. Boxplots of F1, F2, F3 at lateral midpoint with the middle box representing 25–75% data distribution, the middle dot for the mean and the middle line for the median. The white box represents formant and duration ratio data for the retroflex lateral /ɭ/ and the gray box for the non-retroflex lateral /l/.

Kochetov 2018) and several Australian Aboriginal languages (Tabain et al. 2016). In acoustic phonetics, it is considered that retroflexes have a low F3 (Stevens 1998), which has been shown to be the primary acoustic difference between retroflexes and other coronal sounds (Hamann 2003b). In this study, no significant difference for F3 is found between the two
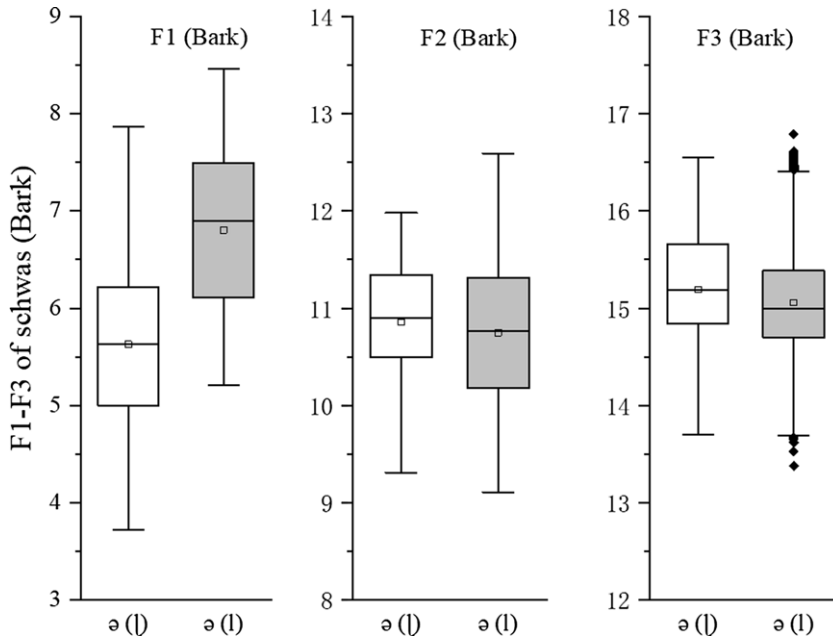
Figure 5. Boxplots of F1, F2, F3 at schwa midpoint with the middle box representing 25–75% data distribution, the middle dot for the mean and the middle line for the median. The white box represents formant data for the schwa following the retroflex lateral and the gray box for that following the non-retroflex lateral.

laterals, with a trend of a lower F3 for the retroflex lateral ($p = .0775$). Individual variation of the two laterals and the following schwas will be shown in detail in Section 3.1.2.

A significantly larger duration ratio is found for /ɭ/ than for /l/, which is inconsistent with studies in other languages where different results are found (duration: /ɭ/ < /l/) in Tamil (McDonough & Johnson 1997), Malayalam and Kannada (Tabain & Kochetov 2018), and no duration difference is found in the three Australian languages Arrernte, Pitjantjatjara and Warlpiri (Tabain et al. 2016). The larger duration ratio of /ɭ/ shows the retroflex lateral in the Zibo dialect holds its lateral closure longer before releasing to schwa in /ɭə/ than /l/, and it takes an average of 72% of the time in the monosyllabic word /ɭə/ compared with an average of 59% for /l/ in /lə/ in this study.

Boxplots comparing F1, F2 and F3 of the two schwas are presented in Figure 5, in which the most obvious difference is shown in F1. The LME results in Table 5 show that the schwa following the retroflex lateral ([əɭ]) has a significantly lower F1 than that following the alveolar retroflex ([əl]) ($\beta = -1.18$, SE = 0.05, $t = -23.70$, $p <$ .0001) and F3 is significantly higher for [əɭ] than for [əl] ($\beta = 0.14$, SE = 0.06, $t = 2.42$, $p = .0246$). No significant difference is found in F2 of the two schwas ($\beta = 0.11$, SE = 0.07, $t = 1.64$, $p = .1170$). The difference in F1 of schwas could have an effect of phonetic cue enhancement in the distinction between the two laterals in the Zibo dialect, which will be explained in detail in Section 4.2.

3.1.2 Individual variation
In this study, we have treated 'Speaker' as a random variable given the relatively large number of speakers involved. In data exploration, it is found that each individual data in the LME models show a large amount of variability, especially for F3 of the laterals (see List S1 for

individual data modeled using LME models in the supplementary materials), suggesting speakers employ a wide range of strategies in the realization of the retroflex and non-retroflex lateral contrast. Inter-speaker variability has been reported in previous studies on both laterals (Nance 2014; Kirkham 2017; Kochetov et al. 2020) and retroflexes (Simonsen et al. 2008; Tabain 2009; Tabain et al. 2020b; Lorenc et al. 2023). Detailed results for the paired sample t-tests of individual data (to show significance of the differences between laterals and between schwas for individual data) and illustrative boxplots of individual variability in F2 and F3 of laterals and schwas are shown respectively in Table A3 and Figures A1–A4 in Appendix B. Analysis of individual production patterns reveals variation in strategies of producing the retroflex-alveolar lateral contrast: speakers F01, F06, F08 (female, aged over 55), speaker F02 (female, aged under 45), speakers M01, M02 (male, aged over 55) and speakers M06, M07, M10 (male, aged under 45) show a significant lower F3 in their production of retroflex laterals than alveolar laterals while speaker F10 (female, aged over 55), speakers F04, F11 (female, under 45), speaker M04 (male, over 55) and speakers M05, M09 (male, under 45) present exactly the opposite result for F3 values in /ɭ/ and /l/.

Despite the variations among native speakers, for all 22 speakers in this study, the duration ratio of laterals is significantly higher for /ɭ/, and F1 of [ə̢ɭ] is significantly lower than that of [ə̢l]; for 19 speakers (except speakers F02, F06 and M04), F1 value is significantly lower for /ɭ/ than for /l/ but with a small difference. This reveals that the strongest and most consistent acoustic cues to distinguish between /ɭə̢/ and /lə̢/ are the larger duration ratio of the retroflex lateral and the lower F1 of the schwa following it.

3.2 Dynamic acoustic analysis and results

The results of SS-ANOVAs are visualized in Figure 6. Since the temporal information is normalized, this does not show any duration information, and only compares the formant trajectories of F1, F2 and F3. The part from Point 1 to Point 11 is the lateral interval and that from Point 11 to Point 21 is the schwa interval. In Figure 6, the formant trajectories obtained from SS-ANOVA analyses are in colored lines with 95% confidence intervals in gray (it is invisible when the CIs are very small). Values in the x axis are time-normalized with C1 marking the onset of the lateral, and C11/V1 marking the end of the lateral and onset of the following schwa.

First, the F1 curve of the retroflex lateral is lower than that of the non-retroflex lateral with a small difference during the whole lateral interval (from C1 to C11), and the F1 curve of [ə̢ɭ] is lower than that of [ə̢l] during the whole schwa section (from V1 to V11) with a notable difference. This result is in line with the findings for F1 at the temporal midpoints of both laterals and schwas in the static analysis. It further illustrates that not only for the formant-stable midpoints of laterals and schwas, a lower F1 is found for /ɭə̢/ than for /lə̢/ over the whole syllable interval. This suggests that the lower F1 found in /ɭ/ is more likely to be an intrinsic acoustic characteristic for this lateral rather than an effect of coarticulation since a lower F1 in /ɭ/ is shown from the very beginning of the lateral segment (C1). Perceptual evidence from further experiments is needed to show whether the statistical significance in F1 of laterals in production is reflected in perception.

Second, the F2 trajectories of two laterals (from C1 to C11) almost overlap with each other; for schwas, the F2 curve of [ə̢ɭ] overlaps with that of [ə̢l] for about the first 20% of the schwa interval (approximately from V1 to V3) and becomes a little higher for the rest part of the schwa interval. This difference is small and does not show a significance at the midpoint of the schwa interval (V6), as shown in the results of the LME models in Table 5.
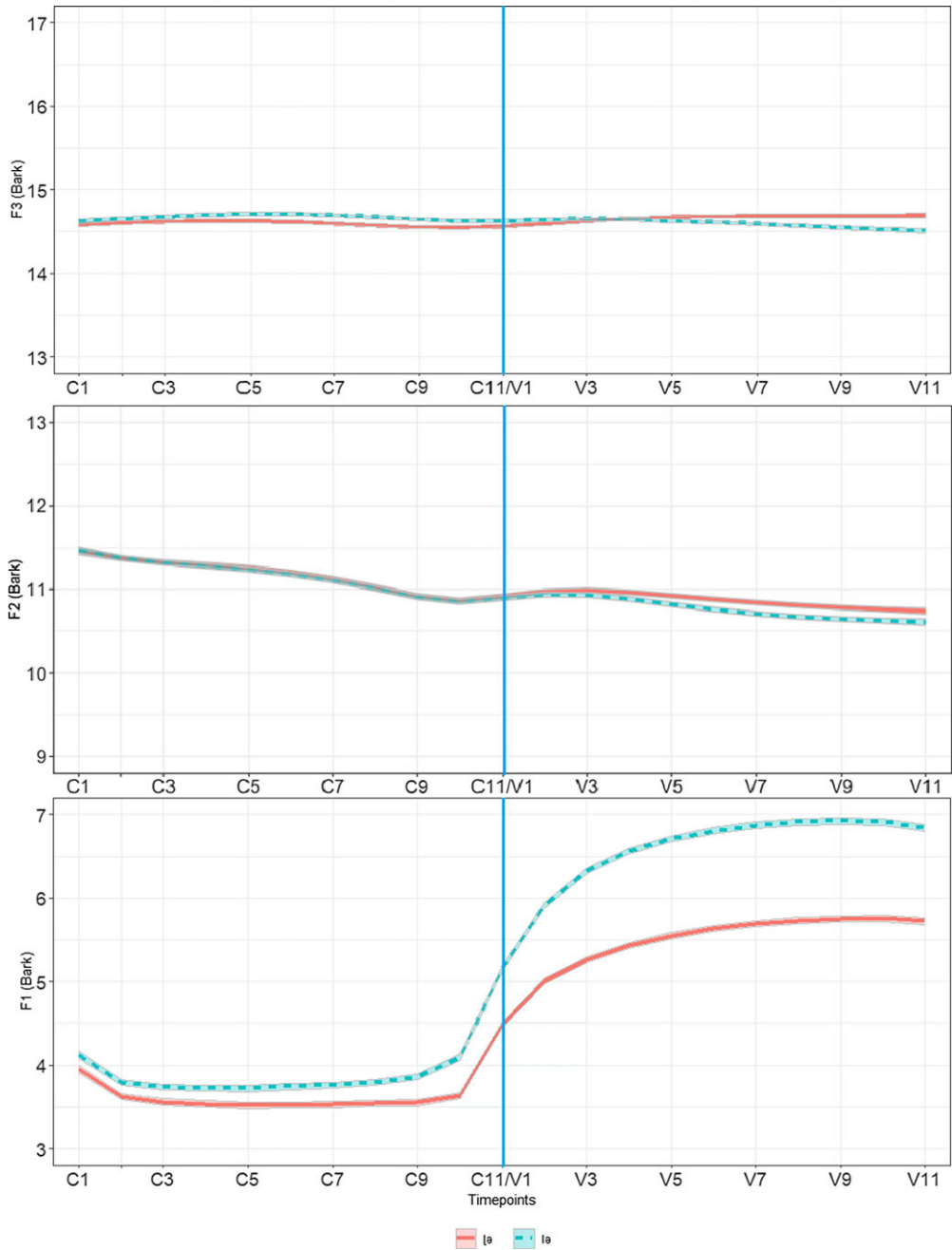
Figure 6. SS-ANOVA of F1, F2, F3 trajectories separately in CV intervals /ləʵ/ and /ləʵ/ with 95% Bayesian confidence intervals shown as a ribbon around the spline. The blue bar at the point C11/ V1 is the boundary between the lateral and the schwa in the syllable, with normalized duration information. The F1 figure is on the bottom, the F2 figure in the middle and the F3 figure on the top. The red solid line is for /ləʵ/ and the green dash line for /ləʵ/.

Third, for F3 trajectories of laterals (from C1 to C11), the formant trajectories overlap at both the initial and final positions but diverge in the middle part of the lateral segment, with /ɭ/ having a slightly lower F3 than /l/. This small difference in F3 of laterals does not show a significance at the midpoint of the lateral interval (C6), as shown in Table 5. For schwas (from V1 to V11), the F3 curve of [ə̺] overlaps with that of [ə̡] at the beginning (from V1 to V3), but the two formant curves begin to diverge at around V3 and the F3 curve of [ə̺] becomes higher than that of [ə̡] for the rest of the schwa interval.

4 Discussion

This section aims to discuss the results reported above by analysing the observed phenomena and providing possible explanations.

4.1 Laterals and the following schwas in the Zibo dialect

In summary, as already reported for the Zibo dialect (Meng & Luo 1994), there are two laterals in this dialect, namely the retroflex lateral /ɭ/ and non-retroflex lateral /l/. /ɭ/ appears in a limited phonemic context: only followed by the mid-vowel /ə/, while /l/ can be followed by most vowels (including nasalized ones) in the vowel inventory. In this production experiment, since /ɭə/ and /lə/ are recorded in the same phonetic context in the carrier sentence, F3 of /ɭ/ is expected to be lower than /l/, as has been reported in the retroflex laterals of other languages (Tamil, Malayalam, Kannada and some Australian Aboriginal languages), and the following schwas might show different phonetic realizations due to coarticulation from different initial laterals. Some findings are unexpected.

Overall, findings in the static acoustic analysis show several acoustic cues presented by all speakers in the production experiment: /ɭ/ has a significantly larger C/V duration ratio in the monosyllabic word and the F1 of [ə̺] is significantly lower than that of [ə̡]. This is in line with Qi's (2019) study of the two laterals in some other dialects in Shandong province. Differently, another acoustic cue found in the Zibo dialect is that F1 of /ɭ/ is significantly lower than that of /l/, and individual data analyses show that 19 out of 22 speakers show a significantly lower F1 in /ɭ/ than /l/, while no significant difference is found in the data of the other three speakers. The difference for F1 of the two laterals is small, and F1 in /ɭ/ is not consistently lower in the retroflex lateral among all speakers, which suggests that F1 of laterals may not be an important acoustic characteristic. No significant difference is found for F2 or F3 of the two laterals. The finding for F3 of the retroflex lateral in the Zibo dialect is consistent with previous studies in the dialects of Chinese (Zhu & Jiao 2006; Dong & Liang 2019; Qi 2019), but is different from studies of retroflex laterals in other languages of the world, e.g., Tamil, Malayalam, Kannada and some Australian Aboriginal languages. The acoustic data also show that the following schwas, i.e. [ə̺] and [ə̡] in this study, show obvious formant differences, especially for F1.

4.2 A phonemic /ɭ/ with evidence from the production experiment

In this study, we support the view that there are two lateral phonemes (/ɭ/ and /l/) in the Zibo dialect and the schwas following the two laterals could be allophones of a phonemic /ə/. The explanations are provided as follows.
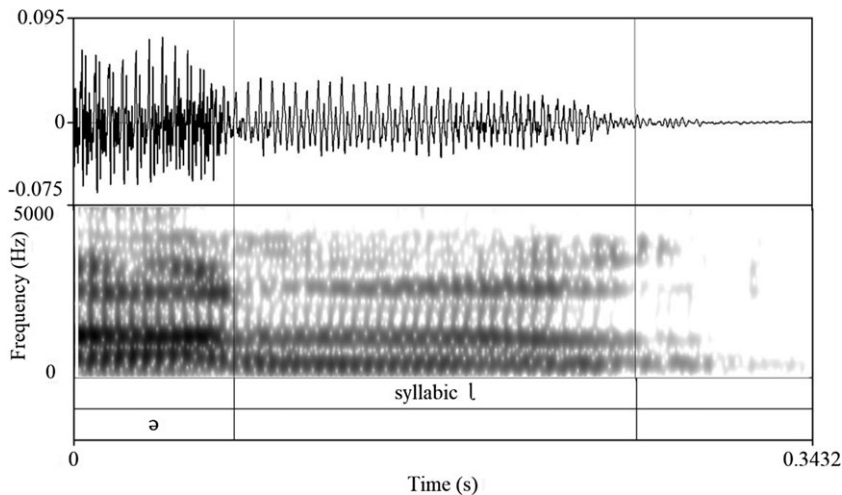
Figure 7. A syllabic /l̺/ production by one male speaker M01, aged 67.

4.2.1 Duration ratio

In the acoustic findings of the two laterals, an obvious distinction is the duration ratio of laterals in the syllable. Segment duration is not a phonological contrast in the Zibo dialect: there is neither a long/short vowel contrast in the Zibo dialect as in Japanese (Hirata 2004) and German (Hertrich & Ackermann 1997), nor does it have consonantal gemination, as is reported in Malayalam (Tabain & Kochetov 2018). Despite this fact, duration of segments is still important since it may affect the clarity of its perception and even compensate for the lack of spectral distinction, as in some Russian vowels (Kouznetsov 2003).

As the retroflex and non-retroflex contrast occurs infrequently or is often neutralized in the word-initial position (Ohala & Ohala 2001; Hamann 2003b; Tabain et al. 2016; Tabain & Kochetov 2018), this study assumes that the longer duration for /l̺/ in the Zibo dialect may have a function of maintaining its distinctiveness from the alveolar lateral and make this segment more perceptually distinguished in the word-initial position. Perceptual evidence is needed to (dis)confirm this point.

In some special cases, several productions of the retroflex lateral by speakers M01, M02 and M04 (all of them aged above 55) are even syllabic, as shown in Figure 7. This echoes with the syllabic /l̺/ reported in Jincheng dialect (Zhu & Jiao 2006). The reason might be that for some elder male speakers, infrequently, they would produce the retroflex lateral with no obvious release of the lateral constriction into the following schwa for ease of articulation. These could be seen as extreme cases when /l̺/ holds for an even longer duration and takes the time of the whole syllable. In this case, an atypical [ə̺] with a higher tongue position would not be necessary to maintain /l̺/'s distinction from /l/.

Moreover, it is recorded in Zhang (1999) and also reported from speakers in this study that when the pronunciation of /l̺ə/ is prolonged, speakers tend to lengthen the /l̺/ part in the syllable; while when the pronunciation of /lə̺/ is prolonged, speakers are more likely to lengthen the schwa in the syllable. By increasing the duration of different parts of the syllable, the distinction between /l̺ə/ and /lə̺/ is made. This could also be a proof of a phonemic /l̺/ in the Zibo dialect.

4.2.2 *Phonetic enhancement and maximum perceptual contrasts*

We may hold the opinion that /ɭ/ and /l/ in the Zibo dialect belong to different phonemes from analyses above, but the acoustic results, especially the dynamic formant curves of /ɭə/ and /lə/, show that the two schwas, considered to be allophones of the same phoneme, show a larger spectral difference than the two laterals as in Figure 6.

The contradiction can be explained by the theory of phonetic enhancement. This theory refers to the employment of secondary phonetic parameters to facilitate the perception of the primary phonetic feature in the implementation of a phonological contrast (Stevens et al. 1986; Stevens & Keyser 1989, 2010; Keyser & Stevens 2006). According to Stevens et al. (1986), groups of distinctive features tend to be implemented simultaneously to form segments, and a given distinctive feature can be represented in a sound with varying degrees of strength, which in turn can be enhanced by its co-occurrence with other features. For example, in English the auditory distinctiveness of intervocalic /b/ and /p/ is signaled by a shorter duration of a silent interval for /b/, while by lengthening the duration of the preceding vowel when producing a /b/, speakers co-vary silent durations with longer preceding vowels to produce a clearer auditory distinction between /b/ and /p/ (Lotto & Holt 2016). The enhancement is more effective when the distinction occurs domain-finally, where the primary distinctiveness is weak (Stevens et al. 1986).

As already noted, the retroflex lateral /ɭ/ is rare, and even rarer in the word-initial position (Steriade 1995; Ohala & Ohala 2001; Hamann 2003b; Tabain et al. 2020a). However, according to Zibo phonology, laterals only occur syllable-initially (also word-initially in monosyllabic words). In order to keep such a weak acoustic contrast in the word-initial position or CV structure perceptible, the contrast is expected to be enhanced by the features of its phonetic context.

Strategies to keep maximum perceptual contrasts are variable across languages, speakers and contexts (Stevens & Keyser 2010). Phonetic enhancement found in the retroflex and non-retroflex contrasts research of an Australian language (Tabain et al. 2020a) is that retroflexes rely on the preceding vowel for correct identification since the differences between retroflex and alveolar nasals are compromised by vowel nasalization. For the retroflex lateral in the Zibo dialect, the place where phonetic enhancement most likely occurs for maximal phonetic contrast is the following vowel, /ə/ in this case. We will explain this from both the temporal and the spectral aspects of the segments.

Literature has shown that the frequency response of human beings' auditory system is not linear, and the auditory system is more sensitive to frequency changes at the low end (between 100 and 1000 Hz) of the audible frequency range than at the high end (between 1000 and 10,000 Hz) (Ladefoged 1996; Johnson 2012). Thus, a phonetic variation below 1000 Hz in the formants of the following schwa can better enhance the distinction of the previous laterals. For /ɭəɭ/ and /ləl/ in the Zibo dialect, since /ɭ/ has a lower F1 than /l/, a lower F1 in its following schwa [əɭ] can co-occur with it to make a robust contrast enhancement.

The vowel charts in Figure 3 also help to explain as a variation, why F1 of [əɭ] is lower than [əl] to fit in the chart. As can be seen, in both the male and the female vowel charts, [əɭ] is lower in the space, and [əl] occurs around the central part of the vowel chart which is less dense. According to vowel dispersion theory (Liljencrants & Lindblom 1972; Lindblom 1986; ten Bosch 1987), vowel systems generally tend to be optimal, in the sense that all vowels must be evenly spread in the available vowel space. It supposes that vowels are distributed in vowel space so as to maximize contrasts. Therefore, [əɭ] is a reasonable variation of [əl] in that it not only fits in the vowel space where the vowel density is small to maximize its contrasts with surrounding vowels, but also has similar F2 with [əl] in the vowel chart.

4.2.3 Geographic and typological factors

Apart from the above explanations, the retroflex lateral /ɭ/ is also reported in some dialects in other cities in Shandong province, such as Lijin, Qingdao, Linyi and Heze (Yang 1990; Qingdao Municipal Archive 1997; Ma & Wu 2003; Qi 2019); for example, in Ma and Wu (2003), /ɭ/ is recorded as being followed by a weak schwa in Linyi dialect. In addition, Gao (2013) has stated that some Shandong dialects have a non-typical weak schwa following the retroflex lateral /ɭ/, and the realizations of this schwa may vary across dialects. Qian et al. (2001) also report that phonologically, a rich inventory of initials (e.g., consonants), a simple system of finals (e.g., vowels) and a simple system of tones are the characteristics of Shandong dialects. Therefore, the typological characteristics of dialects in Shandong support the existence of /ɭ/ in the Zibo dialect. Taking /ɭ/ and /l/ as two phonemes with [əˡ] and [əˡ] as two allophones of the phoneme /ə/ may be more convincing.

4.2.4 Individual variation and a possible change in progress

Although not significant in the results of the LME models for all data, a significantly lower F3 in /ɭ/ is still found in some speakers (five out of 11 speakers in the male group and four out of 11 speakers in the female group), see Figure A1–A4 and Table A3 in Appendix B.

Retroflexion is said to affect mainly higher formants, which are generally lowered (Ladefoged & Maddieson 1996), and specifically the third formant shows a characteristic lowering (Stevens & Blumstein 1975; Hamann 2003b). This is found in language-specific investigations of retroflex consonants (e.g., stops, laterals, rhotic trills) in many languages, such as some Australian languages (Hamilton 1996; Tabain et al. 2016) and Malayalam (Dart & Nihalani 1999; Tabain & Kochetov 2018). Hamilton (1996) claims that the lowered trajectory of F3 is what actually distinguishes retroflexes from other coronals, and the general consensus suggests that a lower F3 is sufficient to distinguish retroflexes from its non-retroflex counterparts. Previous studies of the retroflex fricatives in Standard Mandarin find that this retroflex does not necessarily involve the tongue tip in its articulation and thus shows no kind of bending backwards of the tip at all, which is very different from the same segment class in Tamil (Ladefoged & Wu 1984; Ladefoged & Maddieson 1996; Lee 1999). Its place of constriction is the post-alveolar region, but it differs from the traditional laminal post-alveolar [ʃ] and from the retroflex fricative in Tamil in the shape of its tongue body, which is flatter. Although Lee (1999) refrains from referring to this segmental class as 'retroflex' due to its non-typical retroflex articulation, his finding of a lower frequency range for retroflex fricatives conforms to the phonetic literature of taking the Mandarin post-alveolar fricative as retroflex (Chao 1948, 1968; Ladefoged & Wu 1984; Ladefoged & Maddieson 1996).

Similarly, since the retroflex lateral in the Zibo dialect is not articulated with a subapical articulation or does not necessarily involve bending backwards of the tongue tip, it is not a typical retroflex lateral as that in Tamil or in other languages mentioned above. In the present study, taking into account the fact that averaging results might blur important individual differences (Lorenc et al. 2023), we consider that although no significant difference is found in F3 between the two laterals in the LME models, a lower F3 may still be important for some speakers to distinguish between /ɭ/ and /l/ in their production (see Section 3.1.2). In articulation, retroflexion is traditionally described as an articulation with bending backwards of the tongue (Trask 1996), but differently, Hamann (2003b) has proposed four articulatory characteristics for retroflexion, namely apicality, sublingual cavity, posteriority and retraction. Not all of them are required to occur in the same degree in all instances of retroflex segments, but the more of these properties a segment has, the more

it is like a prototypical retroflex. In this study, the variation in individual data could suggest variability of degree of retroflexion, which would confirm an inherent variability of retroflexes as a sound category. This may also be indicative of a change in process towards disappearance of retroflexion in /ɭ/ and merging of the two laterals.

5 Conclusion

The study has presented an investigation of the acoustic differences between the retroflex and non-retroflex (alveolar) laterals as well as the schwas following the two laterals in the Zibo dialect.

For the first two research questions in Section 1.4, it is found that there is a significantly lower F1 in /ɭ/ than /l/, and the duration ratio of the lateral in /ɭə/ is significantly larger than that in /lə/. No significant difference is found for F2 or F3 of the two laterals. For schwas, it is found that F1 of the schwa following /ɭ/ is significantly lower than that following /l/ and F3 of the schwa following /ɭ/ is significantly higher than that following /l/. In addition, the LME results and individual data inspection indicate that a longer C/V duration ratio and a lower F1 in the following schwa are the most robust acoustic differences between /ɭəɭ/ and /ləl/. Some inter-speaker variation is observed in the realization of /ɭ/, especially in F3, which may be indicative of a change in progress. The answer to the third research question in Section 1.4 is that evidence could suggest that both the retroflex lateral /ɭ/ and the alveolar lateral /l/ are phonemes due to some phonetic differences as well as cue enhancement from the following schwa.

This study has provided acoustic data contributing to the understanding of lateral sounds in general. The results in this study are preliminary and further perceptual studies on the two laterals as well as two schwas are needed to (dis)confirm the results in production. In addition, articulatory research on the retroflex lateral in the Zibo dialect and other dialects in China is also necessary in order to investigate the position of constriction, the tongue shape and movement of the tongue during its articulation.

Appendix A. Wordlists

Note: All the tone values in the Phonemic column are citation tones. The tones of some compounds are realized with tone sandhi in the actual productions, which is not presented here. The target tokens used in this study are extracted where they appear as a monosyllabic word in the carrier sentence (the second /ɭə/ or /lə/ in the carrier sentence), not directly from the compound words. During the recording, speakers read the words shown in random order.

Table A1. /ɭə/ wordlist

Tone		Phonemic	Orthography	Gloss
ɭə	ɭə^2	ɭə^2 ny^2	儿女	son and daughter
		ɭə^2 suɜ̃^{1}	儿孙	son and grandson
		ɭə^2 pɑ^0	耳巴	slap on the face
		ɭə^2 tuə^0	耳朵	ear
		ɭə^2 suei^0	耳碎	earwax
		tʂɜ^2 ɭə^2	找儿	to look for the son
		mu^3 ɭə^2	木耳	agaric
	ɭə^3	ɭə^3 mɜ̃^{0} tʂi^1 tʰəu^0	二门指头	index finger
		ɭə^3 ʂɻ̩^{2}	二十	twenty
		ɭə^3 tʂuŋ^1	二中	No. 2 middle school
		ɭə^3 ʂəu^2	二手	second-hand
		ɭə^3 pu^3 ləŋ^1 tʰəŋ^0	二不楞腾	stupid
		ɭə^3 tɛ^3	二代	the second generation
		ɭə^3 ɕiɜ̃^{1}	二心	disloyalty
		ɭə^3 tʂã^3	二战	the second World War
		ɭə^3 kə^0	二哥	the second elder brother
		ɭə^3 pei^0 vu^2	二百五	fool
		ɭə^3 si^0	二思	hesitated
		ɭə^3 piŋ^2	二饼	a kind of Mahjong tiles
		ɭə^3 tu^3	二度	the second time
		ɭə^3 tʰuŋ^2	二筒	a kind of Mahjong tiles
		ɭə^3 pɜ̃^{2}	日本	Japan
		ɭə^3 tɕʰi^1	日期	date
		ɭə^3 tʰəu^0	日头	sunshine
		ɭə^3 tɕɻ̩^{3}	日记	diary
		ɭə^3 tsʰɑŋ^2	日常	daily
		ɭə^3 lɻ̩^{3}	日历	calendar
		tɕʰiɜ̃^{3} ɭə^3 ku^0 tuŋ^0	跷二古董	strange
		tʂʰɑ^3 ɭə^3 luɜ^3 sã^1	差二落三	to make a mess
		ʂɻ̩^{2} ɭə^3	十二	twelve
		kɔ^1 ɭə^3	高二	senior two
		tɑ^3 ɭə^3	大二	sophomore
		tʂʰu^1 ɭə^3	初二	the second day of a lunar month
		kuɜ^3 ɭə^3	过日（子）	to make a living
		xəu^3 ɭə^3	后日	the day after tomorrow
		tɕiɜ̃^{1} ɭə^3	今日	today

Table A1. Continued.

Tone	Phonemic	Orthography	Gloss
	$l\alpha^3\ p\alpha^0\ l\vartheta^3$	腊八日	the eighth day of the twelfth lunar month
	$x\mathfrak{z}^2\ l\vartheta^3$	好日（子）	good life
	$\text{ʂən}^1\ l\vartheta^3$	生日	birthday
	$\text{miɲ}^2\ l\vartheta^3$	明日	tomorrow

Table A2. /lɚ/ wordlist

Tone		Phonemic	Orthography	Gloss
lɚ				
	lɚ²	lɚ² ʂei³	惹事	to make trouble
		lɚ² lɚ² tʂu³ ɻ³	惹人注意	notable
		lɚ² xuɚ² ʂɔ¹ ʂɤ̃¹	惹火烧身	to bring trouble upon oneself
		lɚ² fa²	惹烦	to trouble
		lɚ² ʂɿ³ fei¹	惹是非	to cause trouble
		tʂɔ¹ lɚ²	招惹	to provoke
		pu¹ xɚ² lɚ²	不好惹	tough
	lɚ³	lɚ³ tu³	热度	temperature
		lɚ³ tɕʰiŋ²	热情	passion
		lɚ³ tɕʰɻ³	热气	hot air
		lɚ³ tɛ³	热带	tropic
		lɚ³ ɕiɤ̃¹	热心	warm-hearted
		lɚ³ tʰuŋ²	热桶	hot bucket
		lɚ³ liɚ³	热烈	enthusiastic
		lɚ³ tʰɑŋ¹	热汤	hot soup
		lɚ³ piŋ²	热饼	hot pancake
		lɚ³ tʂʰɑ²	热茶	hot tea
		lɚ³ ɕiɚ¹	热血	warm blood
		lɚ³ tʂɑ̃³	热战	hot war
		lɚ³ fa³	热饭	hot meal
		lɚ³ tʂuŋ¹	热衷	to be fond of
		lɚ³ tsʰɛ³	热菜	hot dish
		lɚ³ kɑ¹ ta⁰	热疙瘩	heat rash
		lɚ³ fu²	热敷	hot pack
		lɚ³ nɔ⁰	热闹	bustling
		lɚ³ xu⁰	热乎	warm
		lɚ³ ʂuei²	热水	hot water
		tɑ³ lɚ³	大热	very hot
		iɚ̃² lɚ³	炎热	blazing
		tʂʰuɚ² lɚ³	除热	heat extraction
		tsɔ³ lɚ³	燥热	dry and hot
		nɛ³ lɚ³	耐热	heat-proof
		tɕiɑ¹ lɚ³	加热	to heat
		kɚ¹ lɚ³	高热	intense heat
		mɚ̃³ lɚ³	闷热	muggy
		tɕʰiŋ¹ lɚ³	清热	heat-clearing

Table A2. Continued.

Tone	Phonemic	Orthography	Gloss
	$y^2 \, l\partial^3$	余热	remaining energy
	$l\partial\eta^2 \, l\partial^3$	冷热	cold and hot
	$ti\tilde{a}^3 \, l\partial^3$	电热	electric heating
	$f\tilde{a}^1 \, ku\tilde{\partial}^2 \, l\partial^3$	翻滚热	scalding

Appendix B. Paired sample t-test results of individual data grouped by gender and age

Table A3. Paired sample t-test results of individual data at temporal midpoint of /ɭ/ and /l/ and the following schwas [əɭ] and [əᵢ]

|			/ɭ/ and /l/				[əɭ] and [ə₂]		
Speaker No.			F1	F2	F3	DR	F1	F2	F3
Male	Age>55	M01	ɭ< l*	t = 0.88 p = .39	ɭ< l**	ɭ> l***	[əɭ]<[əɭ]***	t = −0.44 p = .66	[əɭ]<[əɭ]***
		M02	ɭ< l**	t = −0.68 p = .50	ɭ< l***	ɭ> l***	[ə₁]<[ə₂]***	[əɭ]>[əɭ]***	t = 0.12 p = .91
		M03	ɭ< l**	t = 0.88 p = .38	t = 0.62 p = .54	ɭ> l***	[ə₁]<[ə₂]***	[ə₁]>[ə₂]***	[ə₁]>[ə₂]***
		M04	t = 0.20 p = .84	t = 0.53 p = .60	ɭ> l***	ɭ> l***	[ə₁]<[ə₂]***	[ə₁]>[ə₂]***	[ə₁]>[ə₂]***
		M11	ɭ< l**	t = −0.22 p = .82	t = −1.32 p = .20	ɭ> l**	[əɭ]<[əɭ]***	[əɭ]>[əɭ]***	[əɭ]>[əɭ]**
	Age<45	M05	ɭ< l***	ɭ> l*	ɭ> l*	ɭ> l**	[əɭ]<[əɭ]***	[əɭ]>[əɭ]***	[əɭ]>[əɭ]**
		M06	ɭ< l***	ɭ> l**	ɭ< l***	ɭ> l***	[ə₁]<[ə₂]***	[ə₁]>[ə₂]***	[ə₁]>[ə₂]***
		M07	ɭ< l***	ɭ> l***	ɭ< l*	ɭ> l***	[ə₁]<[ə₂]***	[ə₁]>[ə₂]***	[ə₁]<[ə₂]***
		M08	ɭ< l***	ɭ< l***	t = 1.70 p = .10	ɭ> l**	[ə₁]<[ə₂]***	[ə₁]<[ə₂]***	[ə₁]>[ə₂]***
		M09	ɭ< l**	ɭ> l***	ɭ> l***	ɭ> l***	[ə₁]<[ə₂]***	[ə₁]>[ə₂]***	[ə₁]>[ə₂]***
		M10	ɭ< l***	ɭ< l*	ɭ< l***	ɭ> l***	[əɭ]<[əɭ]***	[əɭ]>[əɭ]*	[əɭ]>[əɭ]***
Female	Age>55	F01	ɭ< l***	t = −1.35 p = .19	ɭ< l***	ɭ> l***	[əɭ]<[əɭ]***	[əɭ]<[əɭ]**	[əɭ]<[əɭ]***
		F06	t = −0.14 p = .89	ɭ< l***	ɭ< l***	ɭ> l***	[ə₁]<[ə₂]***	[ə₁]<[ə₂]*	[ə₁]>[ə₂]***
		F07	ɭ< l***	t = 1.74 p = .09	t = −1.60 p = .12	ɭ> l***	[ə₁]<[ə₂]***	t = 0.01 p = .99	[ə₁]>[ə₂]***
		F08	ɭ< l**	ɭ> l*	ɭ< l***	ɭ> l***	[ə₁]<[ə₂]***	[ə₁]<[ə₂]**	[ə₁]<[ə₂]*
		F09	ɭ< l**	ɭ< l***	t = −1.77 p = .09	ɭ> l***	[ə₁]<[ə₂]***	t = −0.54 p = .60	[ə₁]>[ə₂]***
		F10	ɭ< l***	t = 1.37 p = .18	ɭ> l***	ɭ> l***	[əɭ]<[əɭ]***	[əɭ]>[əɭ]**	[əɭ]>[əɭ]***
	Age<45	F02	t = −0.63 p = .54	t = 1.31 p = .20	ɭ< l**	ɭ> l***	[əɭ]<[əɭ]***	[əɭ]>[əɭ]**	[əɭ]<[əɭ]***
		F03	ɭ< l*	t = −0.69 p = .50	t = −0.21 p = .84	ɭ> l***	[ə₁]<[ə₂]***	[ə₁]>[ə₂]**	[ə₁]>[ə₂]***
		F04	ɭ< l***	t = 1.41 p = .17	ɭ> l**	ɭ> l***	[ə₁]<[ə₂]***	t = 0.68 p = .50	[ə₁]>[ə₂]***
		F05	ɭ< l**	t = −1.15 p = .26	t = 0.92 p = .36	ɭ> l***	[ə₁]<[ə₂]***	t = −1.88 p = .07	[ə₁]>[ə₂]***
		F11	ɭ< l*	ɭ> l***	ɭ> l*	ɭ> l***	[əɭ]<[əɭ]***	[əɭ]<[əɭ]**	[əɭ]>[əɭ]***

Note: * means $p < .05$, ** means $p < .01$, *** means $p < .001$, the *t*-value and *p*-value are provided where no significant difference is found.
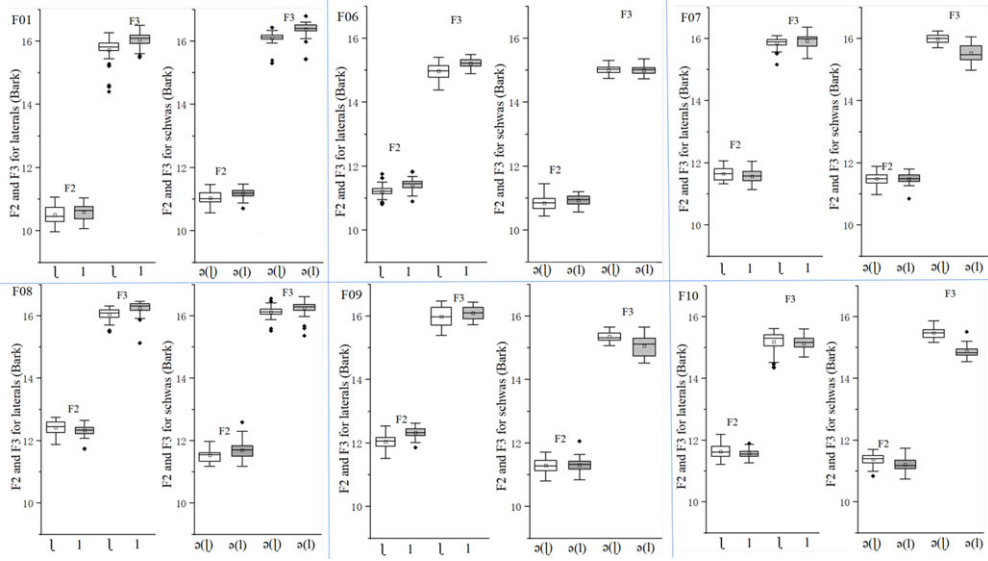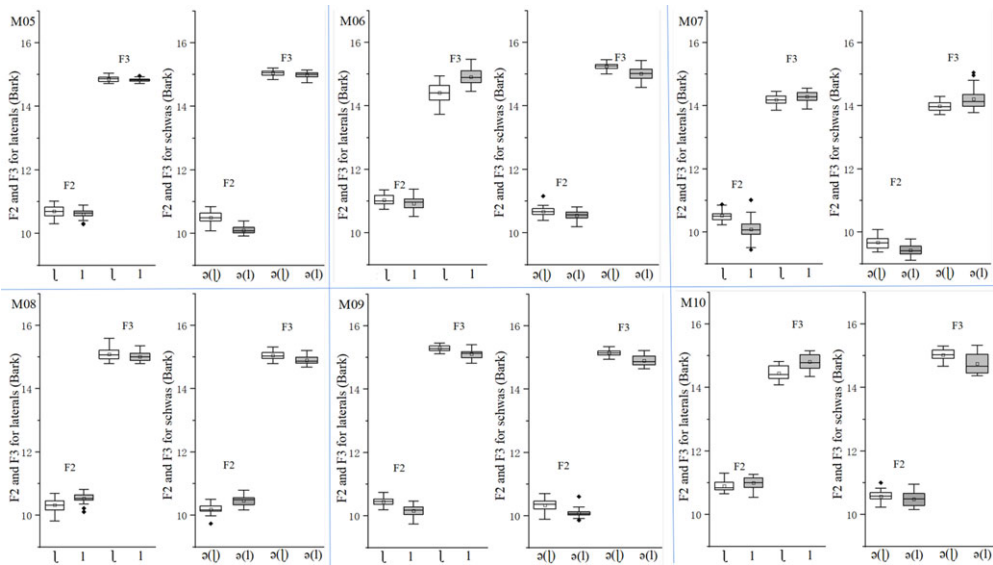
Figure A1. F2 and F3 of the two laterals and two schwas for females in the old group (F01, F06, F07, F08, F09 and F10). The speaker No. is on the upper left of each graph. For each speaker, the left panel is for laterals and the right panel is for schwas. [Female_Old (Age>55)].
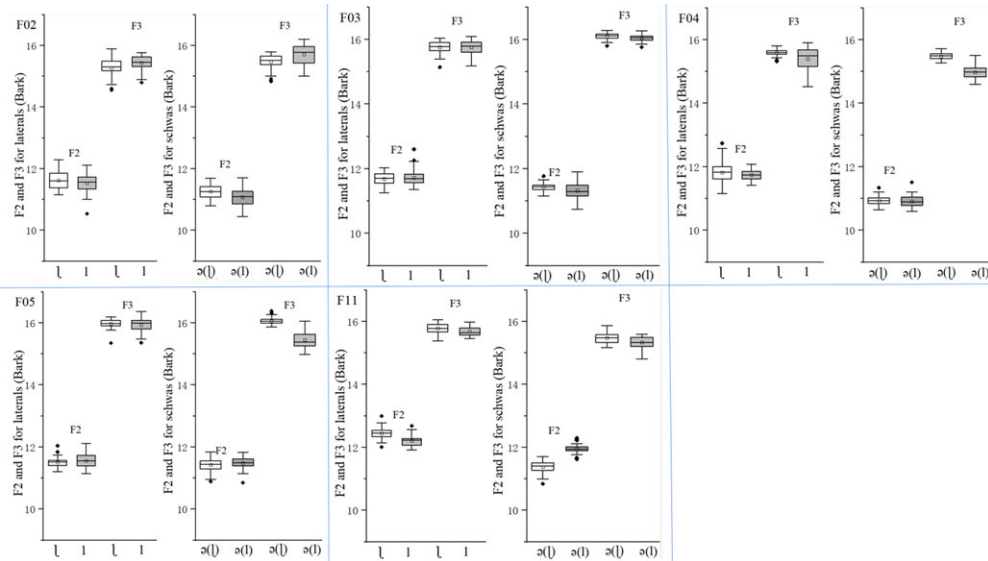
Figure A2. F2 and F3 of the two laterals and two schwas for females in the young group (F02, F03, F04, F05 and F11). The speaker No. is on the upper left of each graph. For each speaker, the left panel is for laterals and the right panel is for schwas. [Female_Young (Age<45)].
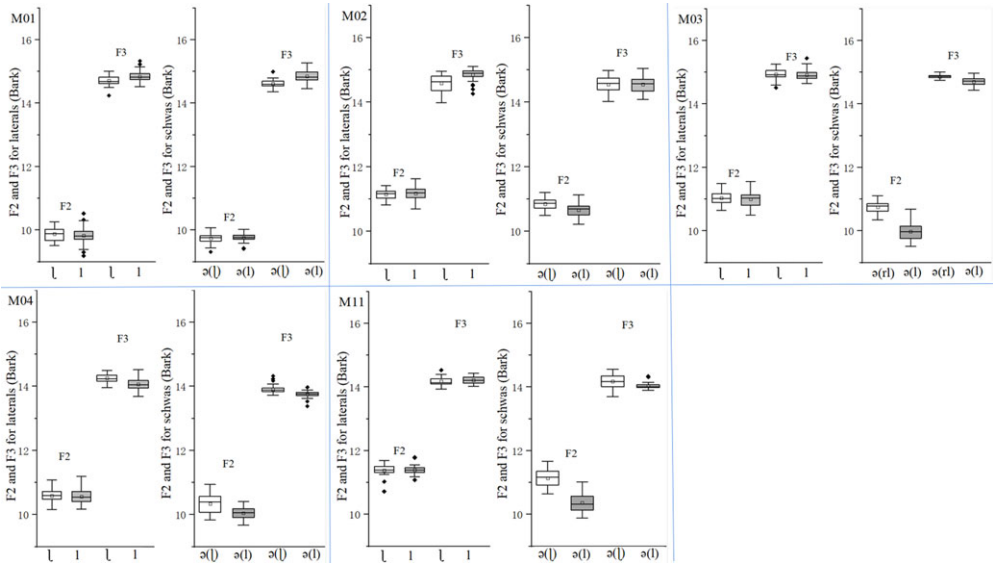
Figure A3. F2 and F3 of the two laterals and two schwas for males in the old group (M01, M02, M03, M04 and M11). The speaker No. is on the upper left of each graph. For each speaker, the left panel is for laterals and the right panel is for schwas. [Male_Old (Age>55)].

Figure A4. F2 and F3 of the two laterals and two schwas for males in the young group (M05, M06, M07, M08, M09 and M10). The speaker No. is on the upper left of each graph. For each speaker, the left panel is for laterals and the right panel is for schwas. [Male_Young (Age<45)].

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