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The interaction between language usage and acoustic correlates of the Kuy register distinction

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Contact is often cited as an explanation for the convergence of areal features and has been proposed as an explanation for the emergence of tonal languages in Mainland Southeast Asia. The current production study probes this hypothesis by exploring the relationship between tonal language usage and the acoustic correlates of the register distinction in Kuy, a Katuic language, as spoken in a quadrilingual (Kuy, Thai, Lao, Khmer) Kuy community in Northeast Thailand. The results demonstrate greater persistence of fundamental frequency (f0) differences over the course of the vowel alongside more tonal language experience for male speakers; however, analysis of individual differences finds that H_1*–H_2*, a correlate of voice quality, is the primary cue for male speakers with greater tonal language experience. For female speakers, a tradeoff is found between f0 and voice quality cues alongside tonal language experience at both the group and individual levels. These findings provide evidence for a model by which contact may serve to enhance existing, non-primary cues in a phonological contrast by shifting cue distributions, thereby increasing the likelihood that these cues will come to be perceived as prominent and phonologized.

1. Background

Areal linguistic features that are shared across genetically unrelated languages are generally understood to result from extended language contact. The literature is rife with examples of contact effects, although in many cases, it is difficult to tease apart the role of contact in language change from a structural predisposition for the given change or from mere coincidence. Closely tied to work on language contact is the experimental literature on bilinguals' usage of L1 phonetic cues in the production and perception of contrasts in an L2 language and of the effects of L2 language exposure and usage on L1 phonological categories. The current study contributes to the intersection of this literature by exploring how variation may be structured by bilinguals' language usage and experience, setting the stage for larger-scale contact effects. The phenomenon of interest is the register contrast in a variety of Kuy (Katuic; Austroasiatic) spoken in Thailand at the borders of Cambodia and Laos. As in other register languages, the Kuy register distinction is characterized by a cluster of cues, including fundamental frequency (f0), amplitude, voice quality (or, more narrowly, phonation), and vowel quality. Speakers, however, differ in the extents to which each cue manifests in the register distinction; the object of study is the relationship between the distribution of cues and language experience and usage patterns, particularly at the individual level.

Kuy populations in Thailand live in a historically quadrilingual society, but the continual increasing centralization of Thailand has pushed language usage to trend largely towards Kuy-Thai bilingualism. As standardization pressures lead Kuy speakers to increasingly shift to the national language, Thai, we expect changes involving cues that are shared between these languages, such as f0, which is the primary cue for the tonal contrast in Thai but only one of several acoustic cues for the register contrast in Kuy. This study delves into individual differences in the interaction between language usage and other social factors and the acoustic correlates of the Kuy register distinction. The goal of this study is to provide a close analysis of how we might understand the macro-effects of language contact on linguistic structure in language used by a community through the micro-effects of bilingualism on the realization of a phonological contrast at the individual level. The results reported in this study show a clear shift in cue prominence in the register contrast that correlates with language experience. I argue that these results show how the rearrangement of cue weights at the individual level can be shaped by patterns of bi- and multilingualism and accumulate to bring about societal-level sound changes that may be understood as language contact effects.

1.1 Cues, contrast, and contact

Tone is one of the most well-known areal features of Mainland Southeast Asia (MSEA), an area that comprises five large families: Sino-Tibetan, Kra-Dai, Hmong-Mien, Austro-Asiatic, and Austronesian (Enfield, 2005, 2011; Henderson, 1965; Matisoff, 2001). In a sample of 186 MSEA languages, Kirby and Brunelle (2017) find that the Sino-Tibetan, Kra-Dai, and Hmong-Mien languages are all tonal. Of the Austroasiatic languages, about one-third have register contrasts, a number of which incorporate pitch, and another third have three or more tones (with many also using voice quality concurrently). The Austronesian languages for the most part utilize neither tone nor register, with the exception of a number of languages (almost all Chamic) that utilize pitch in register contrasts. One Chamic language, Tsat, is not strictly in MSEA, but has a five-tone system (Thurgood, 1999, p. 274). *Tonogenesis*, the emergence of tone, has occurred in a number of languages. Of relevance to the language families of Southeast Asia is tonogenesis in Chinese, sometime between the first millennium BCE and CE (p. 101 (Sagart, 1999, p. 101), and in Kra-Dai, Hmong-Mien, and Viet-Muong around the same time, elucidated through historical and comparative evidence (K. Chang, 1972; Ferlus, 1998; Gedney, 1989; Haudricourt, 1954a, 1954b; Li, 1966; Maspero, 1911, 1912; Mei, 1970; Ostapirat, 2005; Pulleyblank, 1978; Ratliff, 2010). While some sources attribute tonogenesis in these languages to contact with Chinese due to identical-looking tone systems (Benedict, 1996; Matisoff, 1973, p. 88; Pulleyblank, 1986; Sagart, 1999; Ferlus, 2004, p. 307), there is doubt about the source necessarily being Chinese, the tone systems directly being "borrowed," and about contact as an explanation in general (Brunelle & Kirby, 2015; Ratliff, 2015). Ratliff (2015, p. 261), however, leaves room for the possibility of contact making languages more 'tone prone'. The existence of tonal languages in generally non-tonal language families but that are in areas with other tonal languages (Bereznak, 1995, p. 93, Premsrirat, 2001, p. 122, Schuh, 2003, Clements & Rialland, 2008, pp. 72, 74, Hopkins, 2012, p. 423) offers circumstantial evidence for this idea, although there are several languages not in close contact with tonal languages that develop tone as well (Bhatia, 1975; Kanwal & Ritchart, 2015; M. Kim, 2004; M.-R. Kim, 2000; Kingston, 2005; Kirby, 2014; Leer, 1999; Purcell, Villegas, & Young, 1978; Rivierre, 1993, 2001; Silva, 2006; Wayland & Guion, 2005).

The contrast of interest in the current study is that of *register*. Register is a phonological contrast that employs a constellation of suprasegmental features, including pitch, voice quality, and vowel quality (Henderson, 1952, p. 151; Edmondson & Esling, 2006; Ferlus, 1979; Gregerson, 1976; Huffman, 1976). Many languages that have a two-way register distinction may be described as having a modal-breathy, creaky-modal, tense-lax, or stiff-slack distinction: for example, many of which are terms referring to voice quality—the phonetics associated with each of these terms differs in nuanced ways (Gobl & Ní Chasaide, 2013; Gordon & Ladefoged, 2001; Halle & Stevens, 1971; Ladefoged, 1973; Laver, 1980; Maddieson & Ladefoged, 1985). These pairs are often collectively referred to as "high" and "low" register. **Table 1**, adapted from Brunelle, Tạ, Kirby, and Đinh (2020) and added to, summarizes crosslinguistic cues for register from various studies (eg., Andruski & Ratliff, 2000; Bickley, 1982; Blankenship, 2002; DiCanio, 2009; Esposito, 2012; Esposito & Khan, 2012; Garellek, 2012; Keating, Esposito, Garellek, Khan, & Kuang, 2011; Kuang, 2011a, 2011b; Miller, 2007; Pan, Chen, & Lyu, 2011; Thongkum, 1988).

Cue	High Register	Low Register
Open quotient	Lower	Higher
Spectral tilt	Lower	Higher
Harmonics-to-noise ratio	Higher	Lower
Intensity	Higher	Lower
f0	Higher	Lower
F1	Higher	Lower
F2[1]	More peripheral?	More centralized?
VOT	Shorter	Longer
Vowel duration	Shorter	Longer

Table 1: Crosslinguistic correlates of register contrasts.

Tonogenesis is a subtype of a more general process termed *transphonologization* (Haudricourt, 1965; Hyman, 2013), in which "secondary cues" in a phonological contrast come to replace the "primary cues." Transphonologization may begin with enhancement of a secondary cue in a segmental contrast (in the case of tonogenesis, this would be f0), leading to redundant cueing of the contrast alongside the original cue (voicing or voice quality, for example). Following this redundancy, the original cue may be weakened, eventually leading the originally secondary cue to become primary (Hyman, 1976; Maran, 1973). Alternatively, it is possible that the primary cue first weakens, leading to the potential for merger. In this situation, enhancement of another cue may be a strategy to avoid merger, which may be particularly important if the contrast has a high functional load (Baese-Berk & Goldrick, 2009; Wedel, Kaplan, & Jackson, 2013). The following section lays out the linguistic and sociolinguistic details of Kuy to provide the context for understanding how multilingualism can play a role in transphonologization.

1.2 The linguistic landscape of Tambon Tum

The Kuy in Thailand primarily live in the three provinces of Buriram, Sisaket, and Surin, all of which border Cambodia. As a region at the crossroads of three modern countries (Thailand, Laos, and Cambodia) and their predecessors, multilingualism has been the norm for centuries. Following a brief presentation of the phonology of Kuy and the contact languages of the area, I will provide relevant information about the sociolinguistic background of Kuy as background for understanding the intersection of language usage and sound change.

[1] Few studies have looked at F2 systematically (p.c. Marc Brunelle).

1.2.1 Phonology of Kuy and surrounding languages

The current study focuses on Kuy as spoken in Tambon Tum of Amphoe Prang Ku in the Sisaket province of Northeastern Thailand. Discussion of phonology in this section will be limited to facts relevant to the current study, but the reader may refer to Sriwises (1978), Yantreesingh (1980), Suwannaraj (1990), Sangmeen (1992), Sukgasame (2003), Phimjun (2004), and Gehrmann (2016) for fuller descriptions on different Kuy, Kuay, and Nyeu varieties. The consonants and vowels of Kuy as laid out by Phimjun (2004) may be found in **Tables 2** and **3**.[2] Phimjun's inventory is based off data elicited from Kuy as spoken in Tambon Ku, which borders Tambon Tum to the south. This inventory matches what I observed in the Kuy of Tambon Tum (with the exception of the diphthong /ɯa/, which I did not come across).

	Labial	**Alveolar**	**Palatal**	**Velar**	**Glottal**
Stop	p pʰ b	t tʰ d	c cʰ	k kʰ	ʔ
Nasal	m	n	ɲ	ŋ	
Fricative		s			h
Trill		r			
Lateral		l			
Glide	w		j		

Table 2: Consonants of Kuy (adapted from Phimjun (2004, pp. 24–25)).

	Front	**Central**	**Back**
High	i iː	ɯ ɯː	u uː
High-mid	e eː	ɤ ɤː	o oː
Low-mid	ɛ ɛː	ʌ ʌː	ɔ ɔː
Low	a aː		ɑ ɑː
Diphthongs	ia	ɯa	ua

Table 3: Vowels of Kuy (adapted from Phimjun (2004, p. 27)).

Kuy has a two-way register contrast between *modal* and *breathy* voice, a common feature of Austroasiatic languages (Jenny & Sidwell, 2014, p. 53). While this contrast may also be termed high register vs. low register, the current study will refer to these categories as modal

[2] Sources vary on the IPA notation used for the high central (ɯ ~ ɨ), high-mid central (ɤ ~ ə), and low-mid front (ɛ ~ æ) vowels. For consistency, I notate these vowels respectively as /ɯ ɤ ɛ/.

and breathy voice, following previous literature on Kuy. Phimjun does not discuss whether all vowels are represented in both registers; however, Gehrmann (2016) reviews multiple sources, confirming that different Kuy varieties have different restrictions. Kuy in Tambon Tum displays gaps as well, but I have not yet determined all of them. Voiceless unaspirated and aspirated stops are neutralized before breathy vowels, a common feature of Katuic (Diffloth, 1982; Gehrmann & Kirby, 2019; Huffman, 1976). Sriwises (1978, p. vii) and Sukgasame (1993, p. 249) describe modal voice as having a higher pitch overall than breathy voice. Alongside f0 differences, L. Thongkum (1989) also finds higher amplitude in modal voice but conflicting patterns for differences in the first formant (F1) and duration.

Kuy monomorphemic words are maximally of the shape C(V/N̩).CRVC, in which C stands for a consonant, N̩ a syllabic nasal, and R a liquid. The first syllable is limited in three ways: (1) The onset must be simplex, (2) the nucleus must be either a minimal vowel that ranges between nothing and a schwa or a syllabic nasal homorganic with the onset of the second syllable, and (3) there is no coda. One example of a word with the maximal syllable structure is /cn̩trʌ̤ŋ/ ‘diligent’.

The phonological details for Thai, Lao, and Khmer will be restricted to tone and register, which are relevant to this study. Standard Thai has five tones: Mid, low, high-falling, high-rising, and low-rising (Abramson, 1962; Iwasaki & Ingkaphirom, 2005; Tingsabadh & Deeprasert, 1997). Closed syllables with a stop coda may only take one of two tones: If the vowel is short, the tone may be low or high; if it is long, the tone may be low or high-falling. Depending on the variety, Southern Lao may have five or six tones—the Sisaket variety has five tones in open syllables: Low-rising, high-falling, high, glottalized low, and glottalized mid-falling. Closed syllables with a stop coda may be mid-rising or high if the vowel is short, and glottalized low or glottalized mid-falling if it is long (Brown, 1965; Hoonchamlong, 1984, Sipipattanakun, 2014, p. 109). Northern Khmer has neither tone nor register, but like Kuy has a large number of vowels due to the transphonologization of register to vowels.

1.2.2 Sociolinguistic background of Kuy

The Kuy in Thailand are historically quadrilingual in Kuy, Khmer, Lao, and Thai. These four languages exist in a usage hierarchy: In a classification devised by Smalley (1994), Standard Thai [ISO 693-3: tha] sits at the top, being the *national language* taught in schools. Just under Standard Thai is the *regional language*, Northeastern Thai [ISO 693-3: tts], encompassing several varieties spoken in Isan that are contiguous with varieties of Lao [ISO 639-3: lao] in Laos. Linguistically, all these varieties are grouped together as “Lao,” but given the political boundary between Thailand and Laos, there are various sociolinguistic differences between Northeastern Thai and Lao. The Kuy speak a variety of Southern Lao. Next in the hierarchy is Khmer, spoken along the Thailand-Cambodia border, a *marginal regional language* with a sizable population of speakers and which is codified as the national language just across the border. The variety spoken by the Kuy population is Northern Khmer [ISO 639-3: kxm]. At the bottom of this hierarchy is Kuy [ISO 639-3: kdt], a *marginal language* that lacks national status. Kuy is a West Katuic language in the Austroasiatic language family spoken at the border of Thailand, Laos, and Cambodia. It lies in a dialect continuum with Kuay (which shares the same ISO 639-3 code) and Nyeu (or Yeu) [ISO 639-3: nyl] varieties. These groups are also known by the exonym *Suay*. **Figure 1** shows the distribution of the Katuic languages from Diffloth (2011, p. 10). The red arrow I have added points to the Kuy variety, spoken in Tambon Tum, in the current study. I have added country names and borders (in thick black) to supplement Diffloth's map.

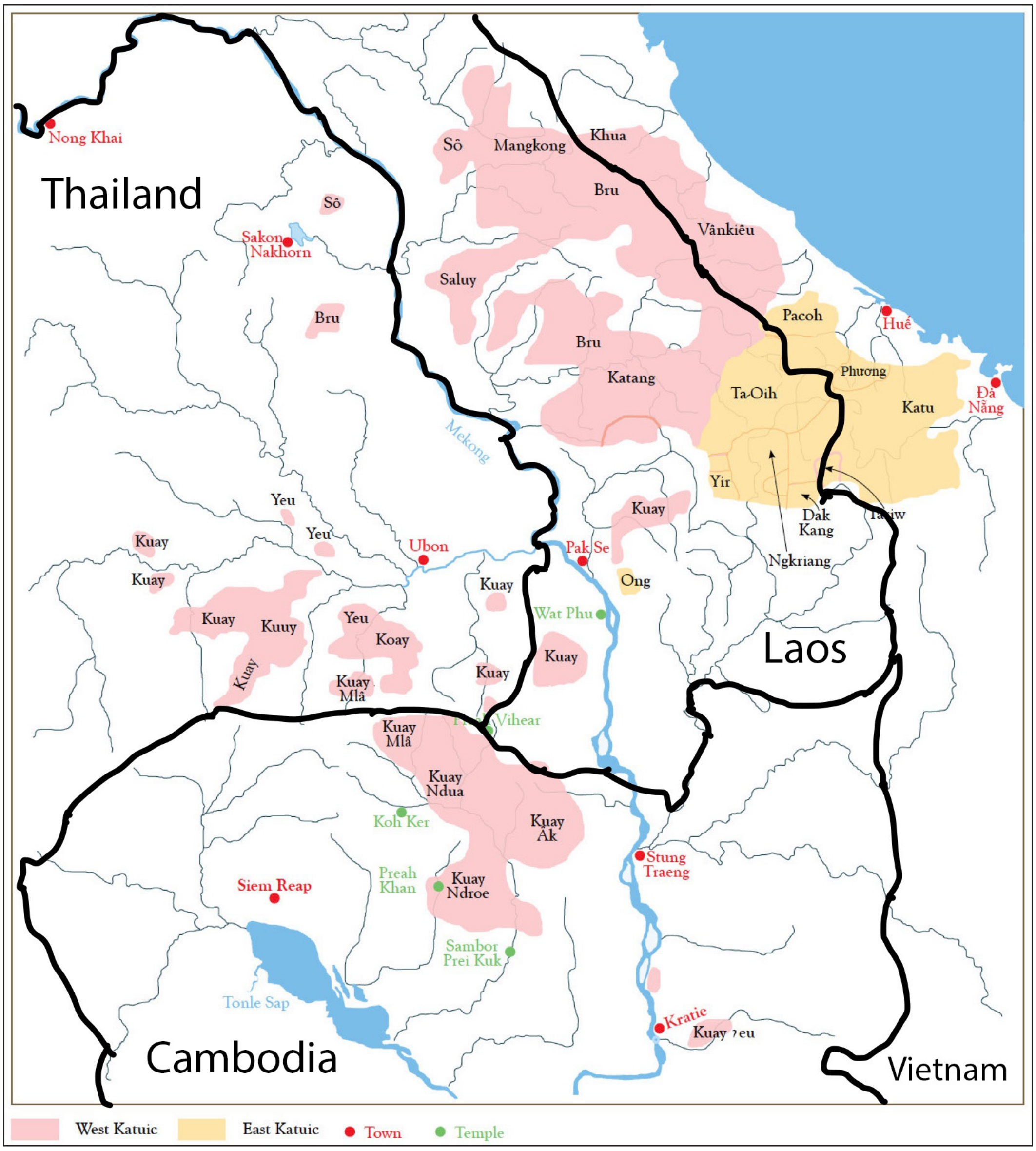

Figure 1: Distribution of Katuic (reproduced with permission from Diffloth 2011, p. 10).

For brevity and clarity, the four languages in this study will be generally referred to as Kuy, Khmer, Lao, and Thai, while admitting that these terms homogenize and oversimplify linguistic and social distinctions. The Kuy have historically assimilated to neighboring Khmer and Lao groups, leading to shrinking of the Kuy-speaking region in recent times, despite growth of the population (Seidenfaden 1952; Yantreesingh, 1980, p. 3; Smalley, 1988, p. 396). Extrapolating from the 2008 General Population Census of Cambodia, there were approximately 28,630 Kuoy speakers in Cambodia in 2008 (National Institute of Statistics, 2009). Chazée (1999) cited approximately 50,000 speakers in Laos. The 2015 census only included counts for ethnic groups who made up at least 1% of the population—extrapolating from this data, there were no more than 64,922 ethnic Kuy in Laos in 2015 (Lao Statistics Bureau, 2015). Premsrirat (2006) cited approximately 400,000 speakers in Thailand. The 2010 census counted 318,012 speakers of local/indigenous languages throughout the country (National Statistical Office, 2015), although this number is likely an underrepresentation. At the time of Premsrirat (2006), the Kuy had an affection for their language, but the use of Lao was seen as more prestigious and was generally the language of choice outside the home.

Demographic data looking at the progression of language shift may be seen in **Tables 4** and **5**. These data are from 117 speakers (and are a superset of the participants in the current study) interviewed in 2018 and 2019. The results are split by generation. **Table 4** breaks down speakers' ability in Khmer and Lao and shows a generational shift in the degree of multilingualism: While the older generation is fully tri- or quadrilingual, there are much fewer quadrilingual speakers in the younger generation and there are even four individuals who are only bilingual in Kuy and Thai. **Table 5** shows self-assessment of speaking ability in each language as compared to Kuy. The most notable pattern is the switch from the majority of speakers rating their Thai ability as less than their Kuy ability (31/59) to the majority of speakers rating their ability equally in the two languages (31/58). While past literature has described Kuy as losing ground to Khmer or Lao, the current numbers show that in recent times, it is primarily Thai to which speakers are shifting.

Age	Neither	Khmer only	Lao only	Both	Total
>45	0	0	4	55	59
≤ 45	4	2	14	38	58

Table 4: Lao and Khmer speaking ability (based on author's survey data).

Age	Thai			Khmer			Lao		
	less	same	more	less	same	more	less	same	more
>45	31	25	3	45	9	1	44	14	1
≤ 45	14	31	13	35	4	1	39	9	4

Table 5: Speaking ability compared to Kuy (based on author's survey data).

Ban Khi Nak School, established up to fourth grade in 1939, is the school that was attended by almost all participants in this sample. Teachers in the past were primarily hired from the local area, so students could use Kuy to varying extents in school with the expectation that teachers would at least understand. However, this expectation no longer holds, as teachers are now mainly recruited from other parts of the country and may not even be aware of the existence of the Kuy as a separate ethnolinguistic group. As schooling was much more limited in the past, many of the older speakers in this sample did not complete school past fourth or sixth grade (established in 1972), as the school was not expanded to ninth grade until 1998 (EMIS 2013, p.c. Sidawun Chaiyapha). Most of the younger population in this study also attended high school nearby and continued to college. Those who continue to college are immersed in Thai by virtue of being in school longer and by living in non-Kuy speaking areas. Lao also serves as a regional lingua franca for those who come from various parts of Isan. Following college, much of the younger population proceed to work in other regions of Thailand, where they use Thai and/or Lao. This continuing trend is facilitated by the continued rapid improvement in transportation infrastructure in Thailand. While spending time in other parts of Thailand was not uncommon in the older generation, it has become much more mainstream. From the same sample as in **Tables 4** and **5**, only 46.67% of women older than 45 had spent any time away from home, as opposed to 65.52% of men. Meanwhile, this gap closes for those below 45, with the proportion being 86.21% for women and 89.66% for men.

The demographic information above shows a clear generational shift in the Kuy population in this study: The younger generation is spending more time in school and in other parts of Thailand. As a result, they use much more Thai and many consider themselves to be equally bilingual in Kuy and Thai, a finding mirrored in Siebenhütter (2020). The language dynamics are changing in Kuy society due to both the average life trajectory of a member of the Kuy community and to the distribution of languages that are now heard in the village, owing to the encroachment of Thai into more linguistic contexts. Many younger parents report using Thai, rather than Kuy, in the home with their children, with a common reason being to expose their children to Standard Thai early for the purposes of succeeding in school; they report that their children can understand, but not speak, Kuy. Due to these shifts in Kuy usage, it is currently classified by Ethnologue as 6b: Threatened (Simons & Fennig, 2017) and as “severely endangered” by UNESCO (Moseley, 2010).

The quadrilingual situation of Kuy is one of intense language contact, a situation that is conducive to language change (Matras, 2009; Thomason, 2001; Thomason & Kaufman, 1988; Weinreich, 1953). These effects are visible at all levels of language, from phonology to syntax to discourse (Aikhenvald, 2007; Field, 1998; Hinton, 1991; King, 2000; Ross, 2007, Meek, 2012, pp. 47, 60) for concrete examples of structural and discourse-level change driven by contact. Changes at the structural level are understood to be a result of bilinguals’ *imposition* of features from one language they speak upon another one (van Coetsem 1988; Winford, 2005). If bilingualism is necessary for structural changes to permeate into a language from another, then an understanding of how bilinguals utilize cues differently from monolinguals is vital to explain how contact may bring about change. L2 speakers of a language use have been shown to use cues differently from monolinguals in both production and perception (Lee-Kim, 2020; Liu & Kager, 2015; Llanos, Dmitrieva, Shultz, & Francis, 2013; Schertz, Cho, Lotto, & Warner, 2015; Stewart, Meakins, Algy, & Joshua, 2018; Vaughn, Baese-Berk, & Idemaru, 2019). Effects are not merely directional from the L1 to the L2; L2 knowledge can also affect shift L1 categories in both perception and production, even with short-term or passive exposure (C. B. Chang, 2010, 2019a, 2019b; Flege, 1987; Gürel, 2004; Sancier & Fowler, 1997).

Given the changing social dynamics and resulting increased exposure to and usage of Thai, which is tonal, alongside the well-documented effects of bilingualism on individual-level phonologies, we may expect f0 usage in the register contrast of Kuy to increase. There are a number of contemporary studies on language contact effects on f0 usage in the context of MSEA. Brunelle (2009) explores cues in the register contrast in three dialects of Cham, demonstrating that Eastern Cham speakers, who are highly bilingual in tonal Vietnamese, show the greatest pitch differences, although Brunelle (2005) finds that younger speakers use pitch less than older ones. Tạ, Brunelle, and Nguyễn (2022) and Brunelle, Brown, and Hà (2022) also look at two register languages, Chrau and Raglai, and find that speakers who are highly fluent in Vietnamese make little use of f0. In exploring the realization of Lao tones by speakers with different language backgrounds in Isan, Pratankiet (2001) finds that Khmer and Kuy speakers show citation form differences from bilingual Lao-Thai speakers, while Sipipattanakun (2014) shows that they have narrower f0 pitch ranges than those who are only bilingual in Lao and Thai. Both linguists attribute these differences to the lack of tone in Kuy and Khmer, but point out as well that differences in some tone realizations may be attributable to influence from Standard Thai.

The effect of Kuy bilingualism on the Thai tone contrast shows substrate effects on a superstrate language. Potential evidence for the reverse comes from a number of studies on the f0 contrast in Kuy. An apparent time study on three Ku(a)y varieties in Thailand and one in Laos by Sukgasame (2003) reveals that the Thai varieties are giving way to a pitch distinction and the Lao ones to a vowel quality distinction in younger speakers. In a follow-up study on two Thai varieties (one of which overlapped with Sukgasame, 2003), Sukkasame (2004) shows similarities between the emergent pitch patterns in these varieties and the tone patterns in the neighboring Lao varieties. A production and perception study by Abramson, L-Thongkum, and Nye (2004) finds that voice quality is a weak cue in production and perception for some Kuy speakers, while Lau-Preechathammarach (2022) demonstrated greater usage of f0 cues for Kuy speakers who use Thai or Lao more than for those who use it less at the group level in both perception and production. These studies together suggest that the Kuy register contrast may be shifting to one that employs pitch more, and that this may be due to influence from Thai or Lao.

2 Hypothesis and methods

This study delves into individual differences in the acoustic correlates of the Kuy register distinction and examines whether the interaction with language usage and other social factors found at the group level is also found at the individual level. Participants who use Thai/Lao more are hypothesized to also use f0 cues more and voice quality cues less in the register contrast, as compared to participants who do not use Thai/Lao as much. A tradeoff is also expected between f0 and voice quality cues, such that speakers who weigh f0 more heavily are expected to weigh voice quality cues less heavily. The goal of this study is to provide a close analysis of how we might understand the macro-effects of language contact on linguistic structure in language used by a community through the micro-effects of bilingualism on the realization of a phonological contrast at the individual level.

In order to test these hypotheses, a production study was carried out in which participants embedded modal and breathy minimal pairs in a carrier sentence. Following the task, speakers were interviewed to gather demographic and sociolinguistic information. Acoustic measures were taken over the course of the target vowels for analysis. Data was transformed by using a principal component analysis to highlight the most meaningful dimensions of variation. Linear regression models were then fitted to estimate the general effects of sociolinguistic factors on trajectories of the acoustic measures. Finally, a linear discriminant analysis was run to determine the acoustic cue weights for each individual and correlations between cue weights and sociolinguistic factors were analyzed to understand speaker patterns.

2.1 Participants

In Tambon Tum, there are three villages with a sizable Kuy population: Ban Khi Nak (Kuy: /t^hrɔʔ k^hnaːk/), Ban Rong Ra (Kuy: /t^hrɔʔ araʔ/), Ban Khi Nak Noi (Kuy: /t^hrɔʔ kɛːt/). According to Kuy speakers in Tambon Tum, these three villages speak the same variety of Kuy. Seventy-five participants were recruited from these three villages in the Fall of 2018 with the help of Thongwilai Intanai, a Kuy speaker from Ban Khi Nak. Participants were explicitly balanced for age and gender, comprising four decades (twenties, thirties, fifties, and sixties) and two genders (female and male). At least eight speakers were sought for each age-gender combination, but given time constraints, extra speakers were also recruited opportunistically, such that some subgroups are overrepresented. Ultimately, nine speakers were excluded from analysis due to failing to complete the experiment (one), extreme difficulty with the task (two), recording issues (four), and producing fewer than ten analyzable unique words (two; see Section 2.5 for determination of analyzability), leaving 66 participants (40 from Ban Khi Nak, 14 from Ban Rong Ra, and 12 from Ban Khi Nak Noi). These participants' ages (subgrouped by decade) and genders are provided in **Table 6**.

	20s	30s	50s	60s
F	8	8	10	8
M	8	8	7	9

Table 6: Participants by age and gender.

A sociolinguistic questionnaire, a translated version of which may be found in Appendix D, designed to capture factors related to language ability, language usage frequency, time spent away from home, and ethnolinguistic affiliation, was administered in Thai following the experimental portion of the study. All speakers are bilingual in Kuy and Thai, and most have at least some knowledge of Lao and Khmer. Only one participant reports not understanding Lao, while six report not understanding Khmer. In terms of speaking ability, three participants report not being able to speak Lao, while 16 report not being able to speak Khmer. All participants are able to read and write Thai, although some older participants have more difficulty doing so. While 20 participants (almost one-third) report never having lived outside of Tambon Tum, there is a fair spread in the time spent away for the remaining 46 participants. The mean and median number of years spent away from home are 5.7 and four, respectively, while the minimum (non-zero value) and maximum numbers are 0.5 and 47, respectively. There is a considerable amount of variation in language usage and ability and in time spent away from home. It is the relationship between this variation and manifestation of the acoustic correlates of register that the current study seeks to probe.

2.2 Wordlist

The wordlist for the experiment included 58 unique words, consisting of 31 target words and 27 distractor tokens (see Appendix A). The target words comprised 12 modal unaspirated vs. breathy pairs, two modal aspirated vs. breathy pairs, and one modal unaspirated vs. modal aspirated vs. breathy triplet. Of the target words, four potentially contain syllabic nasals in the first syllable. In creating this wordlist I attempted to elicit as many minimal pairs (/triplets) as possible, with the help of a dictionary by Sriwises (1978) and a Kuay wordlist from Abramson et al. (2004). However, the resulting list was limited and so words were balanced only for voice quality, but not for segments. I recognize that the imbalance of voice quality may be a confound as phonation differences tend to be greater in low vowels (Brunelle et al., 2020; Kuang & Cui, 2018). The remaining distractor tokens were chosen to observe phenomena for future research: (1) The syllabic nasal (2) the ongoing /tr/ ~ /kr/ merger, and (3) the ongoing coda /r/ ~ /l/ merger. These variables show similar variation in other Ku(a)y varieties (Sukkasem, 2005, p. 50).

2.3 Procedure

The task in the current production study involved embedding each word in a carrier sentence. The sentence was presented in Thai primarily because Kuy orthography is recently developed and few speakers are familiar with it,[3] but secondarily to avoid reading pronunciation. The example sentence presented to participants is in (1). In order to facilitate naturalness, participants were asked to translate this sentence into Kuy and to use that frame for each sentence, only replacing the word "water" with the given word. One common translation of the sentence is in (2). Differences mainly lay in presence or absence of the complementizer /paj/ 'say' and uses of synonyms, such as /kʰam/ for /pna:j/ or /pa:j/ for /waw/. The elicited word retained prominence regardless of the sentence used. The experiment was presented to participants on a Google Nexus 10 tablet and carried out in a quiet room in the temple of Wat Nakharin in Ban Khi Nak. Participants were recorded using an AKG C544-L head-worn condenser microphone connected to an H4n Zoom recorder. Pictures were included with each sentence to aid in elicitation of the intended word. **Figure 2** shows the screen that participants saw for the example sentence with "water," while **Figure 3** shows what participants saw for the trial sentence with "egg."

(1) Example Thai sentence

ฉัน	พูด	คำ	ว่า	**น้ำ**	ให้	เขา	ฟัง
cʰăn	pʰû:t	kʰām	wâ:	**ná:m**	hâj	kʰăw	fāŋ
1SG	say	word	COMP[4]	**water**	for	3	hear

'I say the word **"water"** for them to hear.'

(2) Example Kuy translation (in Mahidol orthography)

ไฮ	เวา	ปะนาย	ไป	**เดียะ**	ออฺน	เนา	จะงัด
haj	waw	pna:j	paj	**diaʔ**	ɑ:n	naw	cŋat
1	say	word	COMP	**water**	for	3	hear

'I say the word **"water"** for them to hear.'

In the training round, the participant first settled on an appropriate translation for the sentence in (1). We then went through each stimulus once as a practice round for familiarization. The participant then completed five rounds alone (generally taking between 15 and 30 minutes in total), with an optional break after the third round. Words were randomized in each round. Participants were told that they could skip a word if they could not remember it. As there were 31 target words and five rounds, 155 target words in total could theoretically be produced.

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[3] There is no widely established orthography yet, although Kuy speakers adapt Thai orthography, with much variation, to spell out Kuy words when texting or using social media. One Kuy orthography that has been developed is an original script by Kuy community member Dr. Sanong Suksaweang, an introduction of which may be found at https://www.youtube.com/watch?v=GUfa0x2tnAw. Researchers at the Research Institute for Languages and Cultures of Asia (RILCA) at Mahidol University have also worked with Kuy speakers in Ban Khi Nak to develop a working Thai-script based orthography, which may be found at http://www.langrevival.com/project/kuy-orthography.

[4] Complementizer.

Figure 2: Example sentence in (1). Instructions above say “Please translate the following sentence into Kuy.” The example Thai word /ná:m/ ‹water› is in red.

Figure 3: Example sentence from task. The example word /ná:m/ ‹water› has been replaced with /k^{h}àj/ ‹egg› (in red). The expected Kuy word is /ṇtrɛ̤:l/.

2.4 Preprocessing of sociolinguistic information

Principal component analysis (PCA) is a technique used to reduce a number of variables to a small number of orthogonal dimensions that capture variance between the variables and is particularly useful when variables are expected to be highly correlated with each other. As much of the sociolinguistic information was expected to be correlated to language usage, a PCA was carried out using the FactoMineR package (Lê, Josse, & Husson, 2008) in R (R Core Team, 2018) to reduce the data to a tractable number of variables for analysis. Many of the variables (see Appendix D) involved frequency of usage or level of ability/identification, all with respect to the four languages/ethnic groups in the area. As such, this data was first consolidated by calculating differences between answers with respect to the atonal languages Kuy/Khmer and to the tonal languages, Thai/Lao, rather than taking the reported values at face value for two reasons. First, participants differed in how "humble" they were with their answers. For example, some participants rank their ability as low in even their most comfortable language, while others are more "confident." Second, the goal was to yield a proxy measure that would capture the *relative* level of Kuy/Khmer usage/ability/identification *as compared to* Thai/Lao. Since there is a heavy right skew for the number of years away people have spent away from home (mean: 5.7, median: 4, skew: 3.12[5]), the number of years was square rooted, yielding a new, less skewed distribution (mean: 1.84, median: 2, skew: 0.57). The transformed sociolinguistic variables that were input into the PCA are explained in **Table 7**. Values were scaled by dividing z-values by two, following Gelman (2008), who proposes this method for statistical modeling to allow for direct comparison with binary predictors.

Factor	Description
Age	Participant's age in years.
√Years Away	Square root of years spent living in another (non-Kuy speaking) area.
Understand	Sum of ability to understand Kuy and Khmer (each coded from 0–4) minus sum of ability to understand Thai and Lao (each coded from 0–4).
Speak	Sum of ability to speak Kuy and Khmer (each coded from 0–4) minus sum of ability to speak Thai and Lao (each coded from 0–4).
Overall Freq	Sum of overall frequency of using Kuy and Khmer (each coded from 0–100) minus sum of overall frequency of using Thai and Lao (each coded from 0–100).
Family Freq	Sum of frequency of using Kuy and Khmer with family (each coded from 0–100) minus sum of frequency of using Thai and Lao with family (each coded from 0–100).
Friend Freq	Sum of frequency of using Kuy and Khmer with friends (each coded from 0–100) minus sum of frequency of using Thai and Lao with friends (each coded from 0–100).
ID	Sum of self-rating of Kuy and Khmer identity (each coded from 0–3) minus sum of self-rating of Thai and Lao identity (each coded from 0–3).

Table 7: Sociolinguistic variables for PCA.

[5] Values over 1 or less than –1 indicate heavy skewness, while values between –0.5 and 0.5 indicate relative symmetry.

2.5 Acoustic analysis

Following forced alignment on the production results using the Montreal Forced Aligner (McAuliffe, Socolof, Mihuc, Wagner, & Sonderegger, 2017), target vowel boundaries were realigned and, for stops, the voice onset time (VOT) boundaries were marked by myself and 12 undergraduate research assistants. For each token, eight acoustic measures were taken over the course of the target vowel using VoiceSauce, a software for calculating voice measures (Shue, Keating, & Vicenik, 2011). These measures are f0, F1, CPP, and five harmonic measures (H_1*, H_1*–H_2*, H_1*–A_1*, H_1*–A_2*, H_1*–A_3*). CPP, *cepstral peak prominence*, is a proxy for *harmonics-to-noise ratio* (HNR). Breathier voice qualities have lower HNR and CPP values (Hillenbrand, Cleveland, & Erickson, 1994). H_n refers to the amplitude of the n^{th} harmonic, while A_n refers to the amplitude of the loudest harmonic in the n^{th} formant. H_1–H_2 correlates with *open quotient*, the ratio of the glottal cycle for which the vocal folds are open, while the H_1–A_n values are measures of *spectral tilt*, the rate of the loss of energy as the frequency of harmonics increase. Higher open quotients and steeper spectral tilt are associated with a breathier voice quality (Gobl & Ní Chasaide, 2013; Hanson, 1995, 1997; Hanson & Chuang, 1999; Henrich, d'Alessandro, & Doval, 2001; Holmberg, Hillman, Perkell, Guiod, & Goldman, 1995). The asterisks following the spectral measures indicate correction for formant frequencies and bandwidths and in order to account for individual differences between speakers (Iseli, Shue, & Alwan, 2007). All of the spectral tilt measures were ultimately combined into one, to be called H_1*($-A_n$*), through a PCA on the five harmonic measures and CPP (see Section 3.2). Ultimately, five measures remained for analysis: f0, F1, CPP, H_1*–H_2*, and H_1*($-A_n$*).

Files were marked for whether the uttered word was the intended target and, for the four words with potential syllabic nasals, whether the nasal was existent (determined by looking for evidence of nasalization in the spectrogram). Minimal pairs were included in the analysis only if the speaker produced at least two tokens of each member of the pair and only if the tokens for each member of the pair matched in presence or absence of the syllabic nasal. For most pairs, this meant that the word with the potential syllabic nasal had to *lack* it (eg., /~~(n̩)~~cʰu:n/ 'to hide' and /cṳ:n/ 'to send'), but in the case of /(ŋ̩)kɛ:ŋ/ ‹waist› vs. / (ŋ̩)kɛ̤:ŋ/ ‹side,› the pair was included only if both words had at least two tokens matching in presence or absence of the nasal. Following this procedure, 5125 files were available for analysis.

Because voice tracking algorithms are sensitive to individual differences, f0 and the first three formants were calculated with speaker-specific parameters. f0 was tracked with the STRAIGHT algorithm (Kawahara, Cheveigne, & Patterson, 1998) through VoiceSauce. Pitch halving and pitch doubling errors were identified and the pitch floor and ceiling were adjusted accordingly. Formants were measured with Praat (Boersma, 2001), also through VoiceSauce. For participants whose f0 values averaged below 150 Hz, the formant ceiling was set at 5500 Hz and the number of formants to be detected was set at 5.5, while for those whose f0 values averaged above 150

Hz, these values were set at 5000 Hz and 4.5, respectively, following heuristics laid out by Skarnitzl, Vaňková, and Bořil (2015). After inspection, the ceiling was shifted as necessary to minimize errors. These f0 and formant values were the basis for VoiceSauce's calculation of the five harmonic measures and CPP. All measurements were taken at every millisecond with a sliding window of 25 ms.

Three more steps were implemented to handle errors following extraction of results with VoiceSauce. First, a moving median filter with a size of 15 ms was applied to smooth out sudden tracking jumps. Second, zero values (0.1% of the dataset) were removed. Finally, z-scores were calculated, using the means and standard deviations for each combination of speaker × vowel quality × voice quality, and values greater than three standard deviations away from the mean (5.2% of the remaining dataset) were removed, minimizing tracking jumps that persisted for longer than the median filter window. Ultimately, 5.29% of the dataset was removed. Because individuals speak at different rates and vowels vary in their length, time was normalized by binning measurements for each file into 20 time intervals and calculating the mean value at each interval. As voice quality measures vary largely across individuals (Biever & Bless, 1989; Davies & Goldberg, 2006; Hanson, 1995, 1997; Hanson & Chuang, 1999; Klatt & Klatt, 1990; Lee et al., 2015; Linville, 1992, 2002; Ma & Love, 2010), the values were scaled by speaker, with Gelman›s (2008) standardization procedure (see Section 2.4), for comparability and statistical modeling. For F1, the values were additionally scaled by vowel height. f0 and F1 Hertz values were also converted into semitones[6] to better approximate auditory distance (Nolan, 2003).

In order to explore group differences and the overall relationship between sociolinguistic factors and the voice quality measures, linear mixed effects regression models were fitted for the scaled values of each voice quality measure with the `lme4` (Bates, Mächler, Bolker, & Walker, 2015) package in R. The model looked at the effect of the interaction of Timepoints (modeled with B-splines using three knots to capture smooth curves with knots at arbitrary timepoints (Curry & Schoenberg, 1966), Register, Gender, Tonal Language Experience, and Time Away (see Section 3.2 for an explanation of the last two predictors) on the five acoustic measures (f0, F1, CPP, H_1*–H_2*, H_1*($-A_n$*)). The maximal model for each measure yielded the lowest Akaike Information Criterion (AIC), so all interactions were kept. Random intercepts were included for Speaker and Word, but random slopes were not included as they led to overfitting.

Individual differences were then explored by quantifying cue weights for f0, F1, H_1*–H_2*, H_1*($-A_n$*), and CPP through the use of Linear Discriminant Analysis (LDA), a technique that involves training a classifier to categorize stimuli into classes given a set of information and labels

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[6] The conversion formula is below, where H_{z0} is the reference Hz value (thus set to 0 semitones) from which the number of semitones is calculated. 75 Hz is the reference value for this study.

$$semitones = 12 \times \log_2 \frac{Hz}{Hz_0}$$

for that information. LDA, carried out through the `scikit-learn` library in Python 3.7 (Van Rossum & Drake, 2009) is the method of choice as it has been shown to be a robust technique for approximating cue weights and therefore is useful for analyzing individual differences in both production and perception studies (Idemaru, Holt, & Seltman, 2012; Schertz et al., 2015; Schertz & Clare, 2020). The data fed into the LDA was the mean value across the 20 time bins for each acoustic measure for each token. The training and test process involved *k*-fold cross-validation, in which the dataset is split into *k* folds, or equal subsets, whose size is $\frac{n}{k}$ rounded up or down to the nearest integer as necessary, where *n* is the size of the dataset. Each of these subsets comprises a test set, while the subset of tokens that excludes the test subset comprises the training set. The classifier is trained on each training set and then applied to the test set. The resulting classification for the test subset is compared to the actual classification to yield an accuracy score. In this study, a classifier was trained, for each individual, to determine whether each token was *modal* or *breathy*, given the acoustic measures for the token. As in the linear regression analyses, the scaled values for all the measures are used. Semitones are used for f0 and F1. A combined accuracy for all phonation measures (H_1*–H_2*, H_1*$(-A_n$*), CPP), henceforth called Voice Quality (VQ), was also obtained by providing the LDA classifier information from these three measures combined. Ten-fold cross-validation was used and the mean of the 10 results was calculated as a proxy for the cue weight of each measure. Pearson's *r* was calculated between these cue weights and Tonal Language Experience to test whether there was a correlation between language usage and production cue weights. Correlations between f0 and the other cue weights were also calculated in order to test whether there is a tradeoff between f0 and other register cues.

3. Results

3.1 Summary statistics

Of the 5125 files, 4542 contained a target word with a stop onset. The means and standard deviations of the voice onset time (VOT) of these stops are summarized in **Table 8** and visualized in **Figure 4**. While the VOT of breathy vowels sits between those of modal vowels following unaspirated stops and modal vowels following aspirated stops, it is much closer to the former (+10 ms) than the latter (–40 ms).

Table 9 and **Figure 5** break down and visualize the means and standard deviations of vowel durations from the data by vowel and voice quality. Scaled values are used because of interspeaker differences. Short breathy vowels are longer than modal ones (note, however, that there are only two short vowel pairs), matching the generalization that breathy vowels tend to be longer than modal ones, but long vowels do not have a consistent pattern. This inconsistency matches the findings of L. Thongkum (1989) for Kuy, who suspects that the durational difference between registers may not occur robustly in languages with a vowel length contrast.

Stop type Register	Mean	SD	n
Unaspirated modal	17	9	1938
Breathy	27	16	2262
Aspirated modal	66	31	342

Table 8: Mean VOT durations (ms).

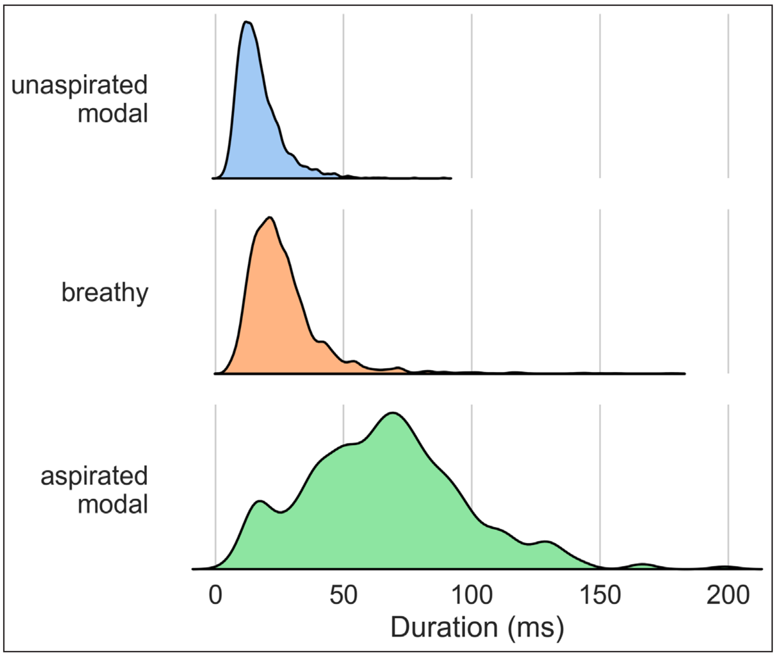

Figure 4: VOT means by stop type and register.

Vowel	Modal			Breathy		
	Mean	SD	n	Mean	SD	n
i:	263	106	447	278	111	429
u:	236	102	718	212	114	733
e:	302	107	228	305	98	211
o:	201	65	440	215	68	430
ɛ:	202	66	61	201	63	55
a	116	36	639	141	45	648
ɑ	89	20	48	106	23	38
Overall	207	104	2581	211	105	2544

Table 9: Mean vowel durations (ms).

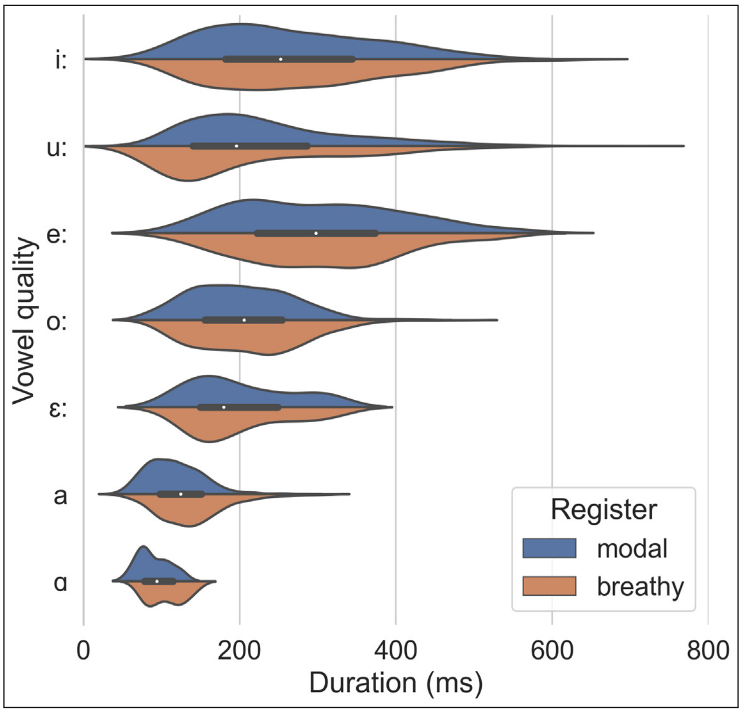

Figure 5: Duration by vowel quality.

Table 10 shows mean f0, H_1*–H_2*, (a robust correlate of voice quality), and F1 values for each vowel, while **Figure 6** shows value trajectories with 95% confidence intervals. Scaled values (described in 2.5) are used to normalize for interspeaker and vowel quality (in the case of F1) differences. Confidence intervals for /ɛ:/ and /ɑ/ are large because they are represented by few tokens. While some register languages, such as Arem (Tạ, 2021), show f0 differences in only some vowels, it is clear that modal voice is higher overall than breathy voice in Kuy, regardless of vowel quality.

3.2 PCA results on social variables and acoustic correlates of voice quality

Correlations between the social variables, the percentage of variance explained by each dimension in the PCA, and correlations between each dimension and each social variable may be found in Appendix B. The first dimension captures 39.51% of the variance and is primarily contributed to by most of the sociolinguistic variables except for frequency of Kuy usage with one's own family and time spent away. Dimension 1 appears to capture ability and frequency of Kuy usage, alongside age, which is unsurprisingly correlated with the former two factors, given the generational shift away from using Kuy. This dimension could be called *Kuy Experience*. However, as the hypothesis is related to usage of a tonal language (i.e., Thai and Lao in this case), this dimension will be negated and referred to as *Tonal Language Experience* (TLE) for ease of interpretation. The remaining dimensions are either primarily comprised of variables that are difficult to cohesively interpret or explain too little of the variance to justify using in the analysis, so they will not be incorporated into the analysis. However, as this study is also interested in the effect of time spent living in non-Kuy speaking areas, the factor √Years Away will be employed in the analysis and will be referred to simply as *Time Away*.

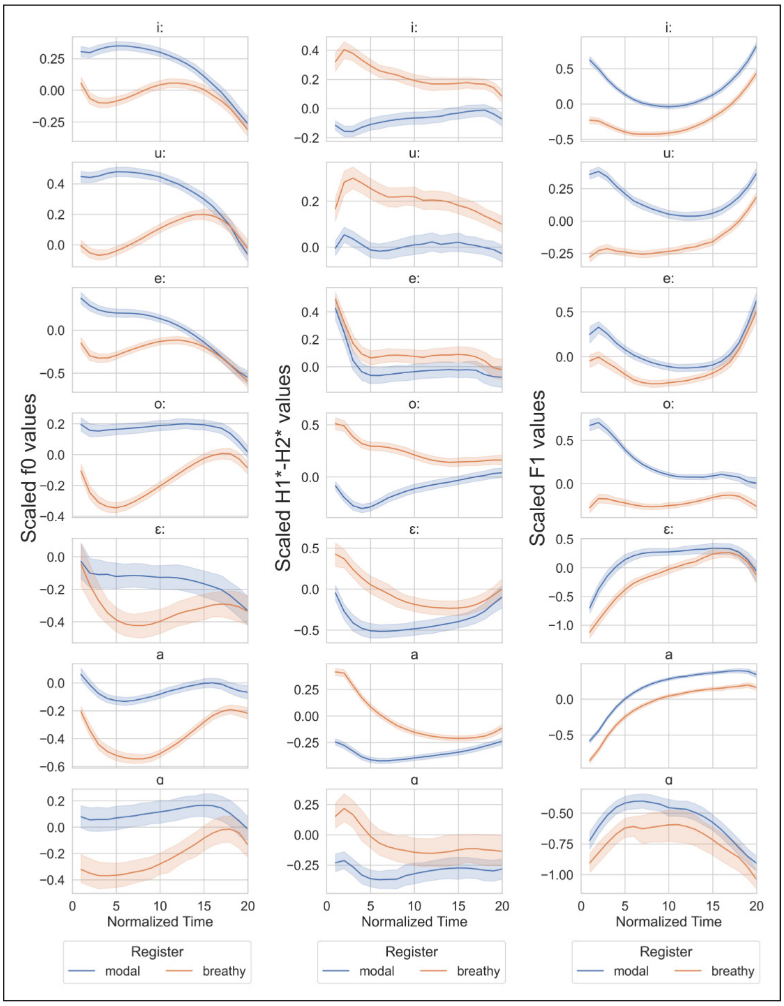

Figure 6: f0, H_1*–H_2*, & F1 trajectories by vowel quality.

Correlations between the voice quality variables, the percentage of variance explained by each dimension in the PCA, and correlations between each dimension and each voice quality variable may also be found in Appendix B. Dimension 1 captures 41.86% of the variance and is primarily contributed to by all H_1*-related values *except* for H_1*–H_2*. This variable will be called H_1* (–A_n). Dimensions 2 and 3 largely correspond to CPP and H_1*–H_2*, respectively, and the rest of the dimensions account for little variation. Thus, only Dimension 1 will be used and CPP and H_1*–H_2* will be treated as separate variables in the analysis.

Vowel	f0 (Hz)	
	Modal	Breathy
iː	174.96	169.16
uː	179.95	170.98
eː	167.92	161.34
oː	175.17	166.46
ɛː	176.86	167.8
a	170.28	161.99
ɑ	192.15	184.38
Vowel	$H_1^*–H_2^*$ (dB)	
	Modal	Breathy
iː	8.08	9.95
uː	8.51	9.55
eː	8.66	9.41
oː	7.9	10.42
ɛː	5.58	8.05
a	5.91	7.99
ɑ	6.55	8.69
Vowel	F1 (Hz)	
	Modal	Breathy
iː	387.54	350.11
uː	379.53	351
eː	450.1	428.26
oː	470.91	424.19
ɛː	600.81	567.13
a	926.32	881.34
ɑ	703.97	649.68

Table 10: Mean f0, $H_1^*–H_2^*$, & F1 values by vowel quality & register.

3.3 Linear model results

Values for the dependent variable for each register at 20 time intervals over the vowel, given values of Tonal Language Experience and Time Away 1.5 standard deviations above and below the mean, were estimated by feeding the linear regression models from Section 2.5 into the `effects` package in R (J. Fox & Hong, 2009). There is significant five-way interaction between Timepoints, Register, Gender, TLE, and Away on f0 ($p < .05$ at Time 1, $p < .001$ at Times 2 and 3), $H_1*(-A_n*)$ ($p < .01$ at Times 2 and 3), and CPP ($p < .001$ at Time 2, $p < .05$ at Time 3). On $H_1*–H_2*$, there is a significant four-way interaction between Timepoints, Register, Gender, and TLE ($p < .01$ at Times 1 and 2, $p < .001$ at Time 3), and between Timepoints, Register, TLE, and Away ($p < .01$ at Time 1, $p < .001$ at Time 3). On F1, there is a significant four-way interaction between Timepoints, Register, Gender, and TLE ($p < .001$ at Times 1 and 3, $p < .01$ at Time 2).[7] The linear regression table for each dependent variable may be found in Appendix C. In order for readers to grasp the magnitudes of the differences, the estimated scaled values were converted back to the original unit by using raw group means and standard deviations for each gender. The back-converted values are calculated by multiplying the estimated scaled value by two times the group standard deviation and adding the group mean. Semitones are converted to Hz. These values are visualized in **Figures 7** through **11**. $H_1*(-A_n*)$ is not reconverted as it is a principal component comprising multiple factors but kept in "half standard deviation" units, as per the scaling method in Gelman (2008). F1 is also displayed in scaled units as the values differ by height. **Table 11** quantifies the mean difference between modal and breathy trajectories for each measure in **Figures 7** through **11**. These mean differences will be referred to as F for female participants and M for male participants.

Differences will be discussed for each measure in turn. **Figures 7** through **9** may each be thought of as representing eight theoretical speakers of the stated gender who would have a TLE score 1.5 standard deviations below (the "less TLE" row) or above (the "greater TLE" row) the mean and who would have spent time away equivalent to 1.5 standard deviations below (the "less Time Away" column) or above (the "greater Time Away" column) the mean: (1) The lower left grids in each figure represent a female and male speaker, to be called the "conservative speakers," who use Kuy, with respect to Thai/Lao, more frequently and/or proficiently than other members of the community and have spent little to no time away from home. (2) The upper left speakers have also spent little to no time away from home, but use Kuy, with respect to Thai/Lao, *less* frequently and/or proficiently than other members of the community. (3) The lower right speakers use Kuy, with respect to Thai/Lao, less frequently and/or proficiently than other members of the community, but have spent much time away from home. (4) Finally, the upper right speakers both use Kuy, with respect to Thai/Lao, less frequently and/or proficiently than other members of the community and have also spent much time away from home. For **Figures 10** and **11**, the bottom speakers would be "more conservative" than the top one; 95% confidence intervals are included for each trajectory.

[7] The four-way interaction between Timepoints, Register, Gender, and Away on $H_1*–H_2*$ is significant only at Time 1 ($p < .05$), and the one between Timepoints, Register, TLE, and Away on F1 only at Time 3 ($p < .05$). Since these effects are significant only at one timepoint, they will not be discussed.

Measure	**Vowel Height**		**Female**				**Male**			
			↓Away		**↑Away**		**↓Away**		**↑Away**	
			Units	**Scaled**	**Units**	**Scaled**	**Units**	**Scaled**	**Units**	**Scaled**
f0		**↑TLE**	13.1 Hz	.47	12.55 Hz	.45	5 Hz	.27	5.22 Hz	.27
		↓TLE	3.37 Hz	.12	5.42 Hz	.19	4.2 Hz	.22	6.06 Hz	.32
CPP		**↑TLE**	2.40 dB	.33	1.46 dB	.2	2.63 dB	.34	.91 dB	.12
		↓TLE	1.01 dB	.14	1.07 dB	.15	.55 dB	.07	.98 dB	.13
H_1^* (– A_n^*)		**↑TLE**		–.26		–.14		–.5		–.25
		↓TLE		–.3		–.36		–.27		–.32
			Female				**Male**			
			Units		**Scaled**		**Units**		**Scaled**	
$H_1^* - H_2^*$		**↑TLE**	–.35 dB		–.04		–3.4 dB		–.55	
		↓TLE	–1.81 dB		–.22		–1.5 dB		–.24	
F1	high	**↑TLE**	32.25 Hz		.36		16.65 Hz		.22	
		↓TLE	27.57 Hz		.31		30.19 Hz		.4	
	mid-high	**↑TLE**	42.67 Hz		”		18.83 Hz		”	
		↓TLE	36.55 Hz		”		34.18 Hz		”	
	mid-low	**↑TLE**	47.06 Hz		”		21.65 Hz		”	
		↓TLE	40.17 Hz		”		39.34 Hz		”	
	low	**↑TLE**	88.61 Hz		”		31.43 Hz		”	
		↓TLE	75.87 Hz		”		57.11 Hz		”	

Table 11: Average differences in predicted means between modal and breathy voice.

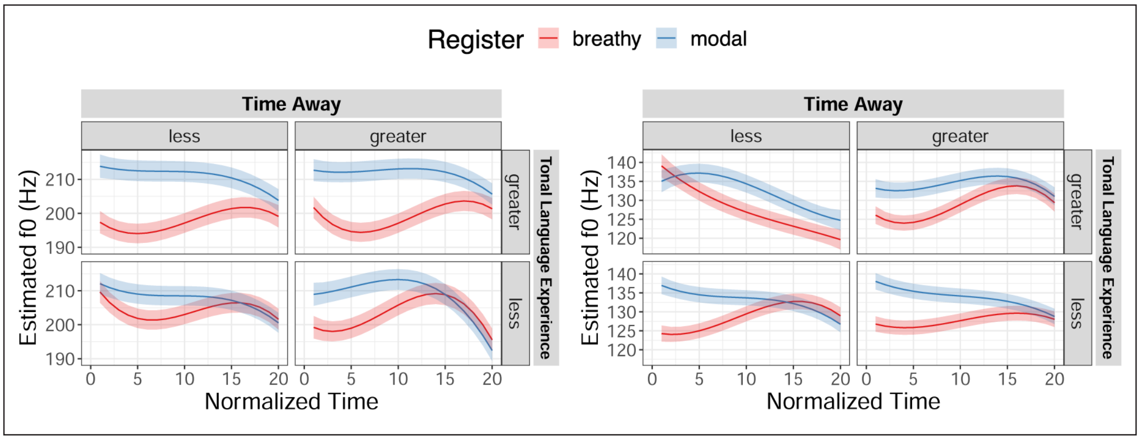

Figure 7: Estimated f0 trajectories for female (left) and male (right) speakers.

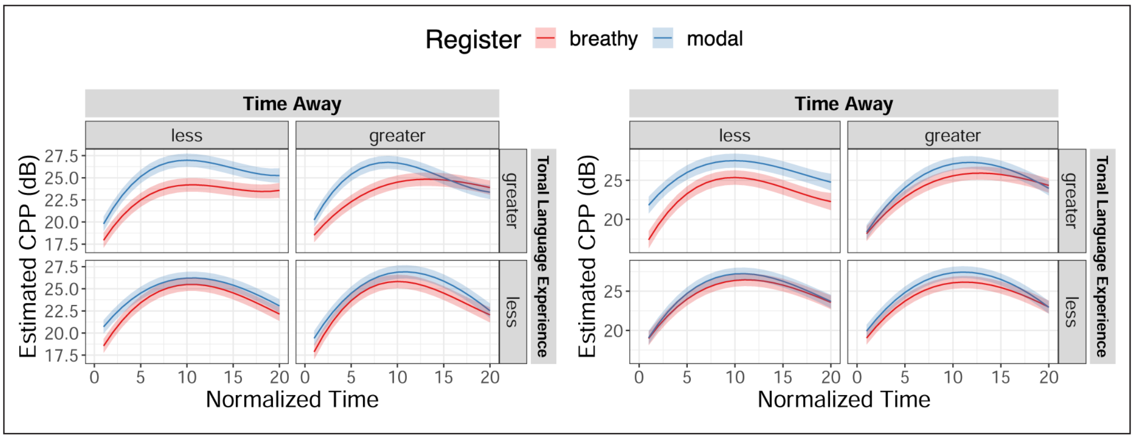

Figure 8: Estimated CPP trajectories for female (left) and male (right) speakers.

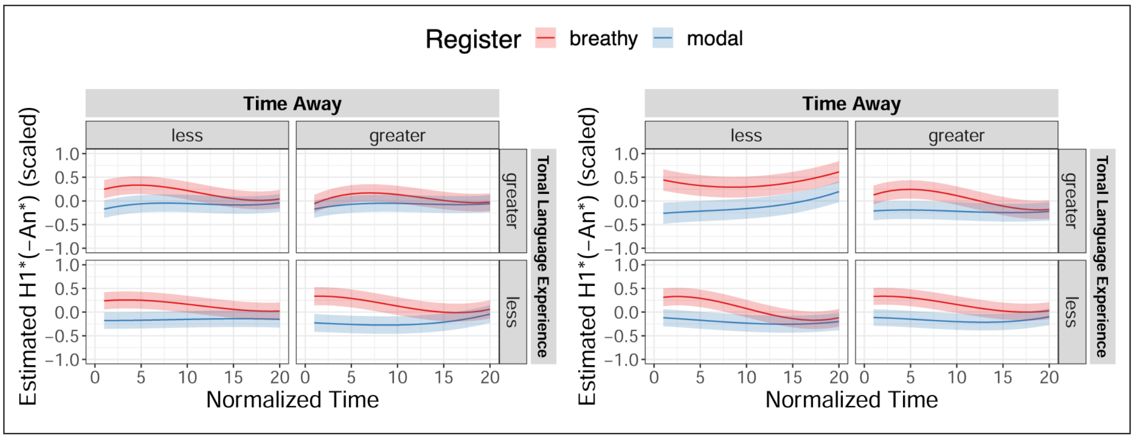

Figure 9: Estimated $H_1^*(-A_n^*)$ trajectories for female (left) and male (right) speakers.

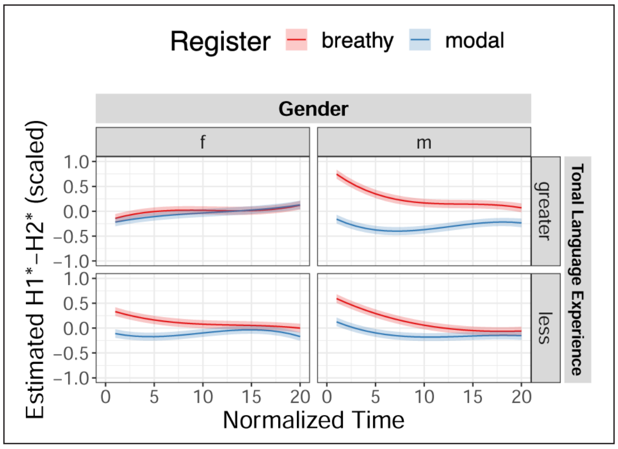

Figure 10: Estimated $H_1*–H_2*$ trajectories.

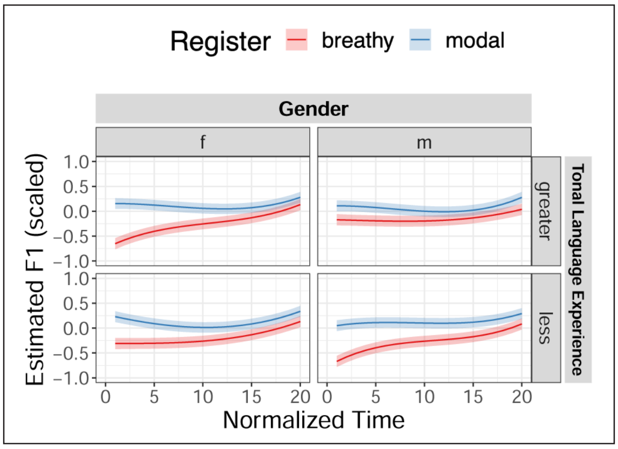

Figure 11: Estimated F1 trajectories.

For both female and male speakers, less Tonal Language Experience (TLE) and less Time Away yield the smallest f0 differences between modal and breathy voice, although they are still significantly different in the expected direction (F: 3.37 Hz; M: 4.2 Hz). For female speakers, greater TLE is correlated with a notable increase in f0 differences, but more Time Away is only correlated with larger f0 differences in the speaker with lower TLE. Meanwhile, for male speakers, greater Time Away is correlated with a modest increase in f0 differences. The largest f0 difference between the registers is seen in the greater TLE, less Time Away female speaker at 13.1 Hz. This value is 9.73 Hz greater than the one for the conservative female speaker. The largest difference for male speakers is seen in the lower TLE, greater Time Away combination at 6.06 Hz, which is 1.86 Hz greater than for the conservative speaker. A noteworthy effect is that greater TLE correlates with the f0 differences between the registers being maintained over more (and as much as all) of the vowel for female speakers.

CPP shows a similar pattern to f0 in that the smallest differences are seen with less TLE and less Time Away (F: 1.01 dB; M: 0.55 dB). For female speakers, an increase of TLE correlates with greater CPP differences between the registers. For both female and male speakers, the greater TLE, less Time Away combination yields the largest differences (F: 2.4 dB, M: 2.63 dB), with the differences persisting over most or all of the whole vowel, like f0. These values are 1.39 dB and 2.08 dB greater than the values for the conservative speakers. Time Away shows mixed differences.

For female speakers, the largest $H_1*(-A_n*)$ differences are seen in the less TLE, greater Time Away combination (–0.36 scaled units), but for male speakers, they are in the greater TLE, less Time Away combination (–0.5 scaled units). An increase in TLE corresponds to a decrease of differences between the registers for female speakers, but there is no clear pattern for male speakers.

$H_1*–H_2*$ differences are smaller for female speakers with greater TLE (–.35 dB) than those with less (–1.81 dB), while male speakers show the opposite pattern as speakers with greater TLE actually have *larger* differences (–3.4 dB) than those with less (–1.5 dB).

F1 differences between the registers will be discussed in terms of scaled units, as these are the same regardless of height. While female speakers with greater TLE show similar F1 differences to those with less TLE (.36 scaled units vs. .31 scaled units), male speakers with greater TLE show smaller F1 differences than those with less (.22 scaled units vs. .4 scaled units).

3.3.1 Summary of group differences

The results reveal a mixed and complicated interaction between the sociolinguistic factors of TLE and Time Away and the various correlates of the modal and breathy registers. However, a number of patterns arise.

For f0, greater TLE shows a clear correlation with *increased differences* between the registers for female speakers. More Time Away is correlated with greater f0 differences for male speakers, while for female speakers, it only correlates with increased f0 differences for the low TLE speaker. Greater TLE is also correlated with the f0 difference persisting over more of the vowel for female speakers. The effect of Time Away on increasing f0 differences appears modest at best.

Greater TLE correlates with smaller $H_1*–H_2*$ and $H_1*(-A_n*)$ differences for female speakers, while Time Away has mixed effects. For male speakers, TLE correlates with larger $H_1*–H_2*$ differences. The decreased $H_1*–H_2*$ and $H_1*(-A_n*)$ differences for female speakers with greater TLE align with the hypothesis, as voice quality cues are weakened. For male speakers however, the increase of $H_1*–H_2*$ with greater TLE is opposite from the expectation. Greater TLE is also correlated with increased differences in CPP between the registers for female speakers, also running contrary to the hypothesis.

Smaller F1 differences are seen with an increase in TLE for male speakers, while female speakers show little difference. The decrease for male speakers aligns with the hypothesis.

In sum, the hypothesis that f0 differences are increased by greater usage of Thai/Lao and more Time Away is supported by the results for male speakers, but only the effect of TLE is supported for female speakers. With respect to the effect of these factors on decreasing the weight of other voice quality measures, the results for H_1-related measures for female speakers and F1 for male speakers corroborate the hypothesis with respect to greater usage of Thai/Lao. Time Away also decreases differences in all the cues for high TLE female speakers. Contrary to the hypothesis, TLE is correlated with greater H_1*–H_2* differences for male speakers.

3.4 Individual differences

The accuracy scores of the LDA classifier for each of the five acoustic measures (f0, H_1*–H_2*, H_1*($-A_n$*), CPP, F1) and the combined VQ measure are treated as proxies for *cue weights* in the following analyses. A value of 0.5 for a given cue would mean that the LDA performed at chance (50%) in classifying register using only information from that cue, suggesting that the cue is completely uninformative in the contrast, while a value of one would mean that the LDA performed perfectly, meaning that the cue is maximally informative. **Table 12** enumerates the number of speakers for which each cue is strongest, split by TLE (less TLE: < 0, more TLE: ≥ 0), while 10 also includes the combined VQ measure. With the VQ cues split up as in **Table 9**, we can see that the most important cue for female speakers is F1 but is H_1*–H_2* for male speakers with greater TLE. The number of female speakers for which f0 is the most important cue jumps from one in those with less TLE to seven in those with greater TLE. **Table 13** shows that all the VQ cues combined are more informative than f0 and F1 for just over half of the speakers (34 out of 66). F1 is the strongest cue for the plurality of female speakers with greater TLE. It is also notable that f0 is the strongest cue for four speakers with greater TLE as opposed to one speaker with less TLE.

Cue	**F**		**M**	
	Less TLE	**More TLE**	**Less TLE**	**More TLE**
f0	1	7	2	2
H_1*–H_2*	2	0	2	10
H_1*($-A_n$*)	3	1	1	1
CPP	0	2	0	1
F1	10	9	11	2

Table 12: Register cue with highest weight (excluding combined VQ measure) by number of speakers, split by TLE.

Cue	F		M	
	Less TLE	More TLE	Less TLE	More TLE
f0	1	4	1	1
H_1*–H_2*	0	0	1	3
VQ	8	6	9	11
F1	7	8	5	1

Table 13: Register cue with highest weight (including combined VQ measure) by number of speakers, split by TLE.

Two hypotheses were tested with the results of the LDA:

1. Higher TLE and greater Time Away are correlated with stronger f0 cue weights and weaker VQ weights
2. There is a tradeoff between f0 and VQ cues

To test hypothesis (1), Pearson's *r* was calculated between each register cue weight and TLE, as well as Time Away. No correlations with Time Away were significant, so these results are not displayed at all. Correlations between each cue and TLE are displayed in **Table 14**. TLE is significantly positively correlated with f0 ($r = .44$, $p < .01$) and CPP ($r = .42$, $p < .05$) accuracy for female speakers. For male speakers, TLE is significantly positively correlated with H_1*–H_2* ($r = .42$, $p < .05$), but negatively correlated with F1 ($r = –.45$, $p < .05$) accuracy.

Measure	F			M		
	r	*p*	Sig.[8]	*r*	*p*	Sig.
f0	.44	.009	**	–.02	.93	
H_1*–H_2*	–.2	.26		.42	.02	*
H_1*(−A_n*)	–.28	.11		.09	.63	
CPP	.42	.01	*	.28	.13	
F1	.14	.44		–.45	.01	*
VQ	–.17	.34		.31	.09	

Table 14: Correlations between LDA accuracy of acoustic cue and TLE.

To test (2), Pearson's *r* was first calculated between f0 and each voice quality cue, the results of which are presented in **Table 15**. The only significant relationships are a negative correlation between f0 and H_1*–H_2* ($r = –.36$, $p < .05$), and between f0 and VQ ($r = –.41$, $p < .05$)

[8] *p*-value significance: * = < .05, ** = < .01, *** = < .001.

Comparison	F			M		
	r	*p*	Sig.	*r*	*p*	Sig.
f0 : H_1*–H_2*	–.36	.04	*	–.21	.25	
f0 : H_1*($-A_n$*)	–.17	.35		.15	.41	
f0 : CPP	–.07	.69		.03	.88	
f0 : F1	–.02	.89		.2	.28	
f0 : VQ	–.41	.02	*	.05	.77	

Table 15: Correlations between f0 and each voice quality cue.

for female speakers. All correlations are visualized in **Figure 12**, with a thick black line and surrounding grey shaded region representing the regression line and a 95% confidence interval for the two significant correlations. The thin black diagonal line ($y = x$) is the identity line—speakers below this line have more accurate f0 scores than the compared acoustic cue, while those above the line have more accurate scores for the compared acoustic cue than for f0. One striking pattern is that female speakers under the identity line are better represented by those with greater TLE (those who lie on the red, rather than blue, end of the spectrum) in *all* the cue comparisons. Male speakers, however, have the opposite pattern when comparing f0 to H_1*–H_2*: Most red speakers lie above the identity line, while those under the identity line are mostly blue. Pearson's *r* was also calculated between F1 and each voice quality cue, but no correlations were significant, demonstrating no tradeoff between F1 and other cues.

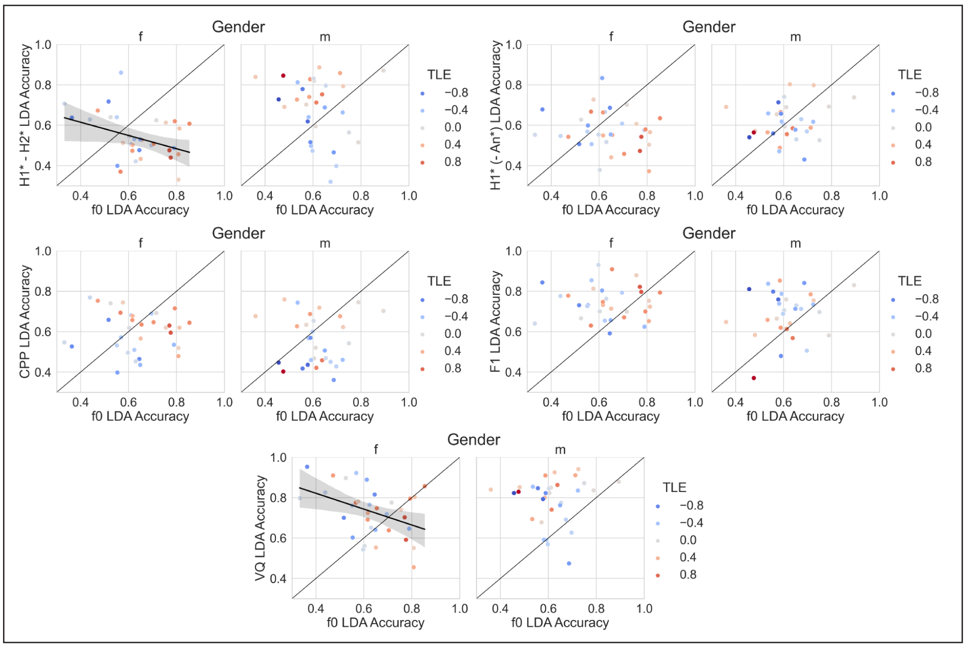

Figure 12: Correlation of LDA Accuracy of each acoustic measure to TLE.

The individual results provide evidence supporting both hypotheses, but only for female speakers. Female speakers show f0 as an increasingly reliable cue over voice quality with greater usage of a tonal language. H_1*–H_2* and VQ both show a tradeoff with f0. The increased usage of CPP in female speakers, however, runs contrary to the hypothesis, although CPP is the strongest cue for only a single speaker. It is also important to note that F1 is a very reliable cue for female speakers regardless of TLE. Male speakers do not behave as hypothesized. While greater TLE does weaken F1 cue weights, it also *increases* H_1*–H_2* weights, and H_1*–H_2* becomes an increasingly reliable cue over f0 with greater TLE. Neither group shows any significant relationships with Time Away on the individual level.

4. Discussion

This production study provides a detailed look into the complicated relationship between the shifting of cue weights and social factors related to language usage. The diversity of language experience in the Kuy population is mirrored in the large variation in cue usage among different speakers and female and male speakers have starkly different patterns.

4.1. Tonal language experience and the register contrast

The results for female speakers show a clear relationship between increased tonal language usage and heavier f0 and CPP cue weighting alongside weakening of H_1*–H_2* and H_1*$(-A_n$*) differences from both the group results as well as in individual patterns. Furthermore, f0 also trades off with H_1*–H_2* and voice quality in general in individuals. Despite the heavier weighting of CPP in speakers with greater tonal language experience, it is the most important cue for only one speaker. The evidence for a relationship between tonal language and f0 cue weighting for male speakers is visible on the group level, but not on the individual level. In Lau-Preechathammarach (2022), pitch halving in a number of modal voice tokens led to the unexpected finding of higher f0 in breathy voice than in modal voice in both female and male speakers with lower TLE and Time Away values. With these values corrected for, the unexpected finding of higher f0 in breathy voice in conservative speakers disappears, although these speakers still show the smallest f0 differences between the registers for both genders. Male speakers show no clear importance for f0 at either the group or individual level. The two relationships that do appear to hold on both the group and individual levels are the decreased weighting of F1 and unexpected increase in H_1*–H_2* weighting with more tonal language usage.

Even with all the voice quality cues combined, the LDA still performs less accurately than for f0 for 17 speakers. Of the 12 female speakers, at the time of the study, two had recently graduated from college, two were teachers, one was a storeowner, and one took up various odd jobs. The remaining half were farmers (an unsurprising number, as 40 out of the 66 participants were farmers). Teachers and graduated students are currently or recently immersed in the Thai education system and the speaker who takes up odd jobs regularly interacts with members of nearby communities, many of whom are not Kuy, but rather Lao, Khmer, and/or Thai. The overrepresentation of these jobs potentially provides some insight into why these speakers may have particularly high f0 cue weights in comparison to voice quality ones, but given the small numbers and the fact that all the male speakers with heavier f0 than voice quality cue weighting were farmers, this idea remains speculative.

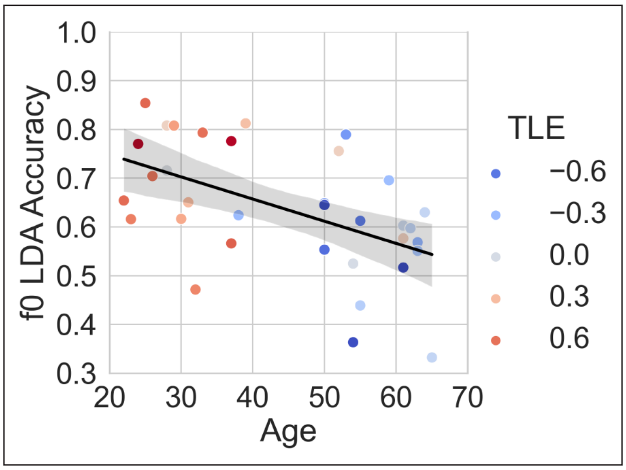

Figure 13: Correlation of age to f0 cue weights.

4.2 Separating age effects from tonal language experience

Given the fact that age is one of the main factors in the TLE principal component, one might wonder whether the shift towards heavier f0 cue weighting in female speakers is merely a generational change, rather than due to language usage. Unfortunately, because age is strongly tied to language usage, with the younger generation using Thai more frequently and proficiently than the older generation, these factors are difficult to tease apart. However, we can inspect variation within age groups. In **Figure 13**, age is plotted against f0 accuracy for female speakers, with points shaded for TLE. Unsurprisingly, there is a strong significant negative correlation between Age and TLE ($r = -.52$, $p < .01$); however, what is also noticeable is that in the 50 to 70 age group, most of the speakers above the regression line are lighter shades of blue than those below the line and there are even two who are shades of red. Meanwhile, within the 20 to 40 age group, the one blue-shaded speaker is below the regression line. The sample sizes are too small to claim that these patterns are necessarily meaningful, but the trend suggests that TLE may be responsible for heavier f0 cue weights *separately* from age. In order to tease these factors apart more, we would need to find more younger speakers with low TLE and more older speakers with high TLE.

4.3 Time away and the register contrast

Time spent away from home appears to have a small effect on male speakers at the group level, correlating with a modest increase in f0 and H_1*–H_2* cue weights. At the individual level, however, no patterns are significant for either female or male speakers, but as mentioned before, this may be because of the lack of time course information for the cue. While TLE captures participants' language usage at the time of the study, the Time Away variable was included in order to capture language usage over a participant's lifetime, as Kuy usage is assumedly much lower in comparison to Thai and potentially Lao usage while away from home. One possibility for the lack of a clear pattern for the effect of Time Away is that it may be too coarse a variable to be an actual proxy for language usage over time. While it is likely that people use less Kuy while living in other places, the extent may differ by individual. For example, it may be the case that many younger people living in other places still use Kuy daily, as smartphones have vastly improved the convenience for remaining in touch with those far away. One's occupation while away from home also influences one's social circles and subsequently one's language usage. Another possibility is that Time Away has little, if any, effect on cue weighting, particularly if the speaker's language usage does not change much, despite being away from the Kuy village. Ultimately, the effect of time spent away from home must be explored in finer detail through a more careful inquiry into the exact nature of people's language usage during the time they spend away from home.

4.4 Gender differences in register cues

The relationship between usage of tonal languages and f0 cue weights in production does not appear to bear out for male speakers. Interestingly, the results in Lau-Preechathammarach (2022) do show that male participants show a clear positive correlation between tonal language usage and f0 *perception* weights on the group level. Where do these differences by gender come from? The key to this puzzle may partially derive from the differences in the histories of female versus male speakers. According to Hesse-Swain (2011, p. 44), migration of Isan people to larger cities as "cheap, unskilled labor" grew following World War II, although gender dynamics have changed over time: In the 1960s, rural migrants were mostly men without spouses or children, but by the 1990s, consisted of all ages and genders. Among the participants that I surveyed in this study, men generally reported traveling to other provinces in order to carry out manual labor, such as cutting sugarcane, while women would tend to be salespeople. This difference in occupation results in different social networks: Men may have tighter social networks due to the isolated nature of manual labor while women may have looser social networks (more weak ties) due to interacting with various customers and other merchants. Differences in social network structure have been linked to differences in the diffusion of linguistic change (Bortoni-Ricardo, 1985; Eckert, 2000; S. Fox, Khan, & Torgersen, 2011; Milroy & Milroy, 1985; Sharma &

Dodsworth, 2020); in this instance, women would particularly be using much more Thai due to the various people with which they would come in contact. Thus, women may show increased f0 differences from using Thai in a variety of contexts due to the nature of their social circles. On the other hand, the social networks of Kuy men may be tighter-knit and largely consist of other Kuy laborers when living in other parts of Thailand.

4.5 Conclusion

The key result of this study is that the usage of a tonal language has the potential to act as a catalyst for tonogenesis, contributing to the understanding of how language contact and bilingualism play a role in sound change through the sharing of cue usage. However, the implications are confounded by the fact that male speakers with greater Tonal Language Experience do not show increased usage of f0, but surprisingly, do show increased usage of voice quality cues. This could mean that either the finding for female speakers is spurious (although note that Lau-Preechathammarach (2022) does demonstrate that male speakers with greater Tonal Language Experience show increased usage of f0 in perception), or that other social factors may be playing a role. The different social circles, largely due to occupation, of women and men, particularly among the older generation who migrated to work in other areas of Thailand, was discussed as potentially playing a role. To test whether this may be the case, future work could attempt to explore the role of social networks by controlling for both gender and social network, either through a detailed investigation of the number of strong and weak ties for each speaker, or through using occupation as a proxy.

The finding of a tradeoff of phonation cues for f0 cues for female speakers is compatible with previous studies by Sukgasame (2003), Sukkasame (2004), and Abramson et al. (2004), who find shifts towards usage of f0 as a cue in the register contrast in other Ku(a)y communities. They also mirror findings by Pratankiet (2001) and Sipipattanakun (2014) by demonstrating that usage of Kuy not only affects usage of Lao, but also vice versa. The shift in cue usage due to knowledge of another language aligns with previous literature on bilinguals' L1 and L2 cue usage. Given the sociolinguistic entanglement of the four languages in the area, however, the different languages that Kuy individuals use cannot easily be categorized into L1, L2, etc. While Kuy was a first language for all participants in this study, it is also the case that many of them acquired other languages simultaneously from a young age, due both to the national status of Thai and the common ethnolinguistic diversity of families and social circles. Although this study can not be cleanly classified as a study on L1 effects on L2 or vice versa, it does speak to the general diffusion of cues across languages within a bilingual speaker. With respect to the question of areal diffusion of tone, I do not take the strong view that Thai or Lao *induce* tone in Kuy, but rather align with Brunelle (2009) and Ratliff (2015) in suggesting that preexisting f0 differences in the register contrast may be *enhanced* through the shared cue usage, thus making Kuy more "tone-prone." This enhancement shifts the complex of register cue weights in Kuy, and while it does not necessitate the contrast to transform into a tonal one, the distancing of modal and breathy f0 distributions may cause listeners to be more likely to identify f0 as a meaningful cue, subsequently increasing the probability of tonogenesis occurring. While Kuy speakers have been in contact with Lao, Khmer, and Thai speakers and have been multilingual in these languages for a long time, it is the current social shifts that have pushed the tides of language usage towards greater usage of Thai in particular. The rich variation in the community offers insights into the mechanisms by which such transitioning behaviors of language usage translate into cue shifts, laying the groundwork for sound change.

Additional files

The additional files for this article can be found as follows:

- **Supplementary File 1.** A ZIP file containing jupyter notebooks and an R script that were used to process the data and carry out the PCA, LDA, and visualizations for this study. More details can be found in the README.md file. DOI: https://doi.org/10.16995/labphon.6531.s1
- **Supplementary File 2.** Appendix A to D. DOI: https://doi.org/10.16995/labphon.6531.s2

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Competing interests

The author has no competing interests to declare.

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