Yang, C. and Xu, Y. (2019). Cross-linguistic trends in tone change: A review of tone change studies in East and Southeast Asia. Diachronica 36:417-459.

Cross-linguistic trends in tone change: A review of tone change studies in East and Southeast Asia

1. Introduction

Understanding of the mechanisms underlying tonogenesis, the birth of tone, has advanced considerably since Haudricourt's (1954) seminal work. However, those same tonogenetic mechanisms cannot fully account for the subsequent development of tonal systems—the splits, mergers, and phonetic tone changes that in Asia have resulted in the emergence of a bewildering diversity of phonetic values from a handful of historical tone categories (Thurgood 2002). Haudricourt (1961) himself noted that tonal systems, once constituted, evolve without reference to their historic origins. Ratliff (2015: 249) sums up what many tonologists have found: "Tones in Asian languages tend to evolve rapidly and *in unexpected ways*" (emphasis added).

In short, our current understanding is limited, and our expectations of how tones should change are not in line with how tones actually do change. Are there directionality constraints on tone change, and if so, what are they?

Haspelmath (2004), concerning the issue of directionality constraints, notes that "diachronic phonologists would benefit enormously from a handbook of attested sound changes in the world's languages." The study of tone change is only at the beginning stages of this endeavor. By observing what tone changes actually happen (and noting which ones rarely or never occur), we can begin to build a diachronic typology of tone change. The present study contributes toward this typology by examining recent or ongoing tone changes across a sample of Sinitic, Hmong-Mien, Tai-Kadai, and Tibeto-Burman languages.

Ground-breaking studies on Bangkok Thai tone change over the past 100 years (Pittayaporn 2007, 2018; Zhu, Lin, & Pachaya 2015) reveal a pattern that Zhu et al. (2015) term the "clockwise tone shift cycle." Pittayaporn's (2018) tone change model, which posits that "diachronic sound changes are the result of phonologization of synchronic patterns of phonetic variation," proposes specific phonetic and systemic biases that may have shaped Bangkok Thai's changes. The present study builds on this recent work, addressing three follow-up questions: (1) Are tone changes like those seen in Bangkok Thai also attested in other languages? (2) What other tone changes are repeated across multiple languages? (3) What phonetic biases (Garrett and Johnson 2013) are most likely to be the origins of the reported tone changes?

The first two of these three questions are empirical, and the present paper addresses them through a comprehensive review of 52 tone change studies on 45 language varieties in East and Southeast Asia.

We then propose an answer to the third question by comparing the patterns of tone change observed in the 52 studies with patterns of contextual tonal variation predicted by the Target Approximation (TA) model (Xu & Wang 2001; Xu 2005) and its quantitative implementation (qTA) (Prom-on, Xu, & Thipakorn 2009). We conclude that there is a strong match between tone change trends and the patterns of synchronic tonal variation found in connected speech.

The results of the review demonstrate strong cross-linguistic trends in phonetic tone change. Specifically, clockwise changes, the pattern observed in real time in Bangkok Thai, are by far the most common type. The cross-linguistic dominance of this type suggests that this pattern is not language-specific, but rather is attributable to language-general mechanisms of tone production and perception. Pittayaporn's (2018) phonetic and systemic biases are reflected in most of the tone changes found in the review. However, his model could be improved by adding phonetic biases of carryover effects and truncation, important sources of contextual tonal variation in connected speech. Carryover effects are the progressive, typically assimilatory, effects that preceding tones have on following tones (Xu 1997). Truncation is the premature termination of tone articulation due to lack of sufficient time (Xu 2017).

Reasoning about tone change through the lens of contextual tonal variation—a method initiated by Hyman and Schuh (1974) and continued by Pittayaporn (2007, 2018) and in the present study—is an important but neglected approach to the question of directionality constraints. Hyman (2007) observes that discussion of neighboring tones' effect on contour is "strikingly missing." Unlike segmental and phonation effects on pitch, which typically occur within one syllable, carryover effects and truncation become visible only across multiple syllables in connected speech; this may be one reason why contextual variation's role in tone change has not yet been given sufficient scholarly attention. To explore the implications of contextual variation for tone change, it is necessary to use a model of tone production such as the TA/qTA model that simulates the contextual variants of tones in connected speech. TA is derived from systematic acoustic analysis of contextual tonal variations (Xu 1997, 1999, 2001). There are also other potentially relevant models, such as Autosegmental-Metrical (Pierrehumbert 1980, 1981) and Command-Response (Fujisaki 1983). Because they are not originally derived from empirical research on contextual tonal variations, they will not be considered in the present paper.

The remainder of the paper is structured as follows. After reviewing prior work on tone variation and change, we present a cross-linguistic review of the aforementioned 52 tone variation and change studies, seeking to discover trends in tone change across East and Southeast Asian languages. We then demonstrate that tonal truncation generates synchronic variation that matches the diachronic patterns. We therefore propose, as a possible answer to the third research question above, that truncation may be a key mechanism in tone change. Truncation, in fact, may be the underlying trigger for Pittayaporn's (2018) phonetic biases of peak delay and contour reduction.

2. Previous research on tone change

2.1. Patterns of tone change

Bangkok Thai holds a unique position in tone change studies, as one of the few tonal languages with recordings dating back over a century, with the earliest acoustic evidence coming from Bradley (1911) and Jones (1918). Pittayaporn (2007, 2018) and Zhu et al. (2015) examine the changes that have occurred in the phonetic values of Bangkok Thai tones from the past century to today. These are groundbreaking studies, because examining changes as they occur in real time provides the most direct and reliable evidence for the directionality of change (Bybee 2015: 9).

The findings are quite striking. Tone 3 (C1), previously mid falling, is now high falling; Tone 4 (C2), high with a subsequent sharp fall, is now mid rising; Tone 5 (A1), mid rising, is now low falling-rising (with truncated variants). Zhu et al. (2015) additionally suggest that even Tone 2 (B1) has undergone change: it was low level in Bradley (1911) but is now phonetically a low falling tone. The more recent changes are also documented in multiple apparent-time studies (Teeranon 2007; Zsiga 2008; Thepboriruk 2009). See Figure 1 for Pittayaporn's (2018) summary of the changes that have occurred over time.

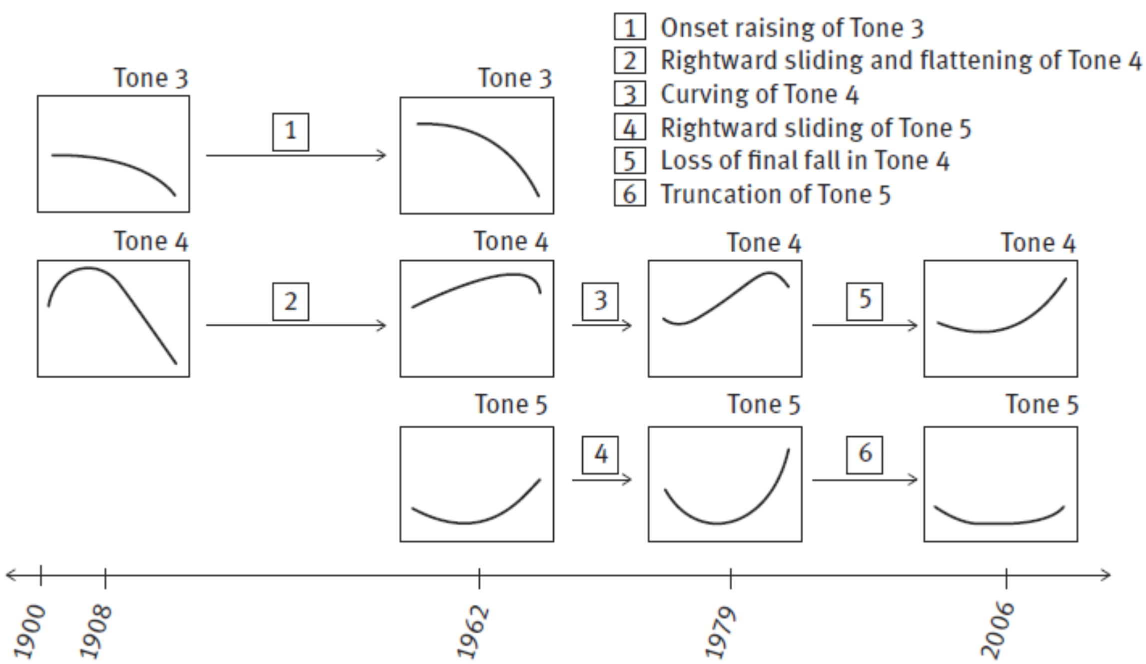


Figure 1: Tone changes in Bangkok Thai. Reproduced with permission from Pittayaporn (2018).

Zhu et al. (2015) suggest that the Bangkok Thai tone chain shift is not unidirectional but cyclical, in what they term the "clockwise tone shift cycle." In other words, it is possible that Tone 5 (formerly rising, now low with truncated rise) is headed toward where Tone 2 was 100 years ago (low level), while Tone 2 may move into the space once occupied by Tone 3 (mid falling). If so, the Bangkok Thai tone system will have completed a complete clockwise cycle, in the sense that each of the tones in question will have proceeded through at least one stage of the cycle. The cycle as presented by Zhu (2018) is as follows; the numbers following the rule represent the Chao pitch number notation for tones, ranging from 1 (low) to 5 (high):

(1) Clockwise tone shift cycle: {32>42>52>55>45>35>24>23|323|32}

Zhu's (2018) clockwise cycle does not explicitly deal with rising-falling tones, but it could be easily expanded to accommodate the rising-falling contour reported for Bangkok Thai Tone 4 in the mid-twentieth century (Brown 1965, cited in Pittayaporn 2018): high falling > high level or rising-falling> rising, etc. The resulting expanded clockwise cycle is as follows (see also Figure 2):

(2) Expanded clockwise cycle: low level 11|22> low falling 32 > mid falling 42 > high falling 52 > high level 55 or rising-falling 453 > mid rising 45|35 > low rising 24|13 > falling-rising 323|214 or low level 11|22 > low falling 32, and so on

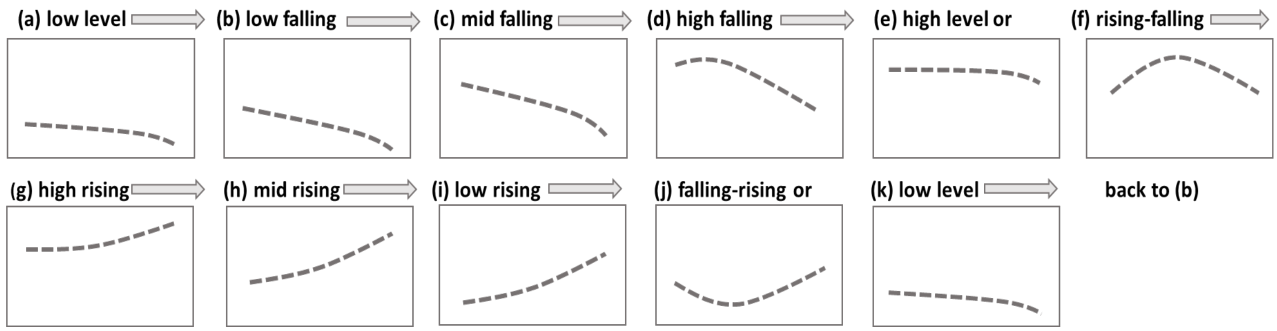


Figure 2: Schematic of individual tone changes in expanded version of Zhu's (2018) clockwise cycle

Comparing Figure 1 (Bangkok Thai changes) and Figure 2 (clockwise changes), one sees that a change of Tone 5 to low level would close the loop, returning to where Tone 2 began 100 years ago. One can summarize the loop as follows:

(3) Tone 2 low level > low falling (not in Figure 1, Figure 2 (a) > (b))

(4) Tone 3 mid falling > high falling (Figure 1 [1], Figure 2 (c) > (d))

(5) Tone 4 high falling > rising-falling > rising (Figure 1 [2], [3], [5], Figure 2 (d) > (f) > (g))

(6) Tone 5 rising > falling-rising > low falling-rising with truncated rise (Figure 1 [4], [6], Figure 2 (h) > (j) > almost (k))

The clockwise pattern developed by Zhu et al. (2015) represents an important new idea in the Chinese tone change literature, which constitutes the majority of existing scholarly work on tone change. The idea of a tone chain cycle is not new, dating back at least to Hirayama (1998), but the clockwise pattern goes in the opposite direction of Hirayama's proposed tone chain shift. In his research on Dezhou Chinese tone sandhi (sandhi is the phonological, categorical alternation of tones), Hirayama hypothesizes that (1) the sandhi form of the tone reflects the tone's phonetic value at an earlier historical period and (2) the citation form is diachronically innovative. This assumption leads Hirayama to posit the following diachronic push chain cycle: the offset of high level tone falls lower due to reduction, becoming a falling tone; this change pushes the falling tone to low falling, which pushes the low falling tone to a low falling-rising tone, which pushes the low-falling-rising tone up to a high level. Hirayama's chain of shifts can therefore be summarized as follows:

(7) high level > high falling > low falling > falling-rising > high level

Although Hirayama's cycle involves the same stages of change as the clockwise cycle, the directionality is opposite or "counterclockwise" (Zhu 2018). Hirayama's counterclockwise pattern is based on attributing a diachronic dimension to the relationship between citation and sandhi forms, but tone sandhi is known to have a non-transparent relationship to both synchronic contextual variation and diachronic change (Zhang & Liu 2011). Nevertheless, this pattern has influenced later work on tone change in Chinese dialects, such as the studies by Zhang and Zhu (2017) on Hui-Pu Min and by Zhu and Li

(2016) on Meizhou Hakka. These studies entail recording citation tone forms at multiple field sites across one dialect area, normalizing the acoustic data, and then examining the geographic distribution of tonetic variants. In both studies, one field site's tone system is posited as the most conservative, followed by reasoning as to how the other field sites' systems could have evolved from it. Both studies suggest that counterclockwise changes have taken place, and Zhang and Zhu (2017) cite Hirayama's counterclockwise pattern as support for their proposed evolution paths. But the directionality of change is most reliably established by observing sound change in progress or in real time. Therefore, the clockwise pattern has stronger support, as it has actually been observed in real time.

Hyman (2017) proposes several other diachronic tone change patterns: (1) tones spread perseveratively ("horizontal assimilation"); (2) contour tones level out ("contour simplification"); (3) L-H sequence intervals tend to compress ("vertical assimilation"); and (4) H-L sequence intervals tend to expand ("polarization"). We will discuss horizontal assimilation and polarization further in the next section. Vertical assimilation occurs when low level before high level becomes mid level (L H > M H), and when high level after low level becomes mid level (L H > L M). Simply put, both high level and low level regress to mid level in certain environments. Figure 3 below presents a schematic of these patterns, with the leveling pattern on the left and the regress to mid pattern on the right:

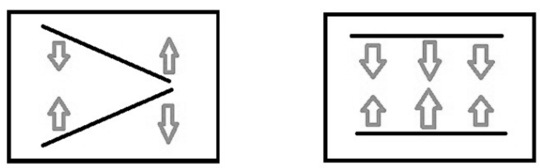


Figure 3: Leveling pattern (left); regress to mid pattern (right)

2.2. Phonetic origins of tone change

In his examination of Bangkok Thai tone changes, Pittayaporn (2018) adopts a phonetically based approach to sound change, in the tradition of Ohala (1993, 2003), Beddor (2009), Garrett and Johnson (2013), and others. In this approach, sound change is a process in which (1) phonetic biases in speech production and perception generate orderly variation in speech; (2) systematic biases favor or disfavor those variants, after which the favored variants may then become phonologized in individuals' grammar; and (3) the innovative variant may eventually become adopted as a norm in the community. Pittayaporn (2007, 2018) proposes several phonetic and systemic biases that influence tone change directionality:

Phonetic biases:

1. Peak delay: tone peaks tend to slide rightward rather than leftward.
2. Contour reduction: F_0 excursion of tonal contours tends to decrease; affects pitch offsets only.
3. Segment-tone interaction: an initial segment's interaction with tone affects pitch onsets only.

Systemic biases:

1. Contour maximization: tonal variants with greater F_0 excursions will be selected for phonologization; affects pitch onsets only.
2. Contour accentuation: a new feature, such as an initial drop before a rise, is selected to enhance the auditory distinctiveness of a tone.

3. Avoidance of similar tones: tones within a tone system tend to be dispersed in phonetic space so as to maximize perceptual contrast.

As will be seen in Section 3, these biases, especially the phonetic biases of peak delay and contour reduction, appear to play a role in many of the tone changes in the review. However, the model does not explicitly incorporate two important sources of tonal variation in connected speech: carryover effects and truncation. The Target Approximation Model (Xu & Wang 2001; Xu 2005; Xu & Liu 2012) does incorporate these phenomena; therefore, at this point we will briefly describe the TA model and how it represents these two sources of variation.

The TA model has three key features: (1) surface realizations of tones are the result of sequential approximations of underlying pitch targets; (2) each target approximation movement is synchronized with the syllable, and (3) the beginning state of an approximation movement is determined by the end state of the preceding syllable's target approximation, or by a default neutral value (if after silence or a voiceless segment) (Xu & Liu 2006). Figure 4 illustrates the model.

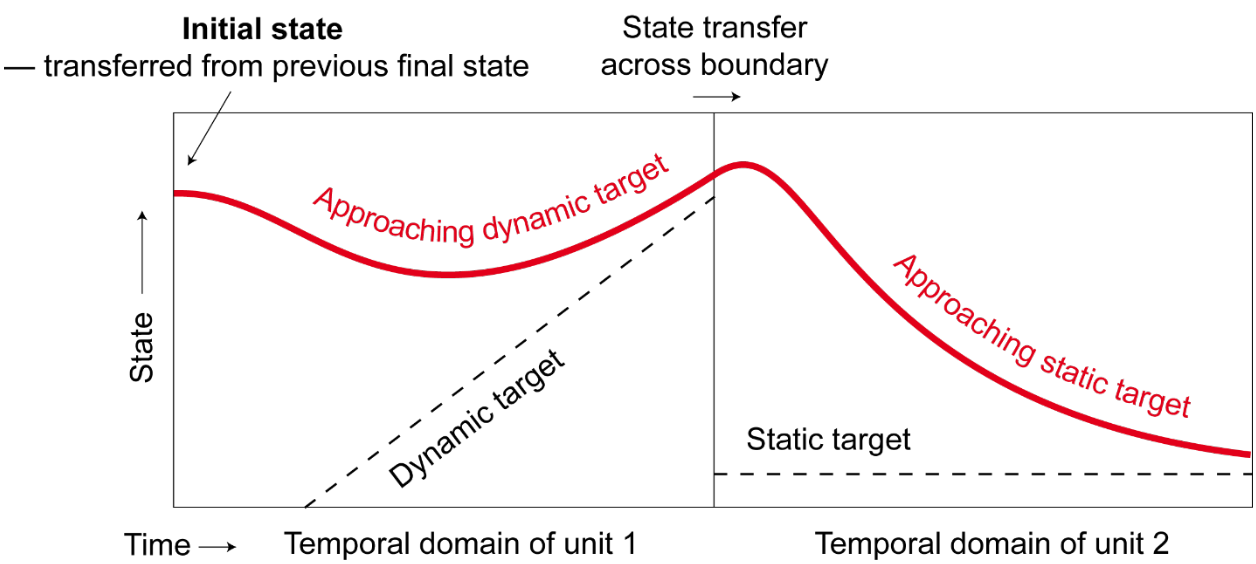


Figure 4: Target Approximation Model (Xu & Liu 2006; reproduced with permission). The vertical lines represent syllable boundaries; the dashed lines represent underlying pitch targets; the dark lines represent the surface realization of the tones.

TA is based on empirical studies of tone production (e.g., Xu 1997; Xu 2001; Xu & Sun 2002; Xu & Wang 2009). As an example, Figure 5 shows contextual variation in Mandarin tones during production of a two-syllable sequence, "ma-ma" (from Xu 1997). Mandarin has four tones: High (Figure 4, top left, second syllable), Rising (top right), Low (bottom left), and Falling (bottom right). In each panel, the first syllable's tone varies and the second syllable's tone is kept constant. As Figure 5 illustrates, the pitch height at the end of the first syllable determines the beginning pitch of the second syllable's tone. The approach to the second syllable's pitch target begins from this initial state, which necessarily shapes the target approximation movement. High is often approached through a rising trajectory, Low through a fall, Rising through a fall-rise, and Falling through a rise-fall.

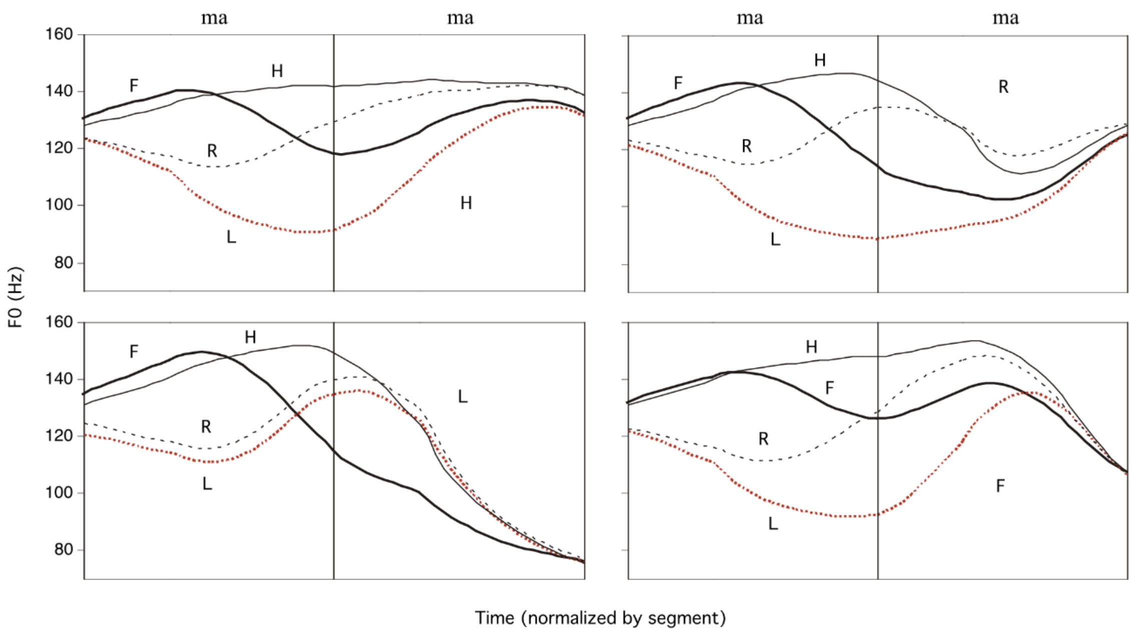


Figure 5: Contextual variation of Mandarin tones; mean F_0 contours in actual production (48 tokens per sequence, 6 repetitions x 8 speakers). The dashed vertical line represents the syllable boundary; lines of various colors represent the surface realization of F_0 contours. Source: Xu (2004), adapted from Xu (1997).

The transfer of the end state of a preceding syllable to the initial state of a following syllable, seen clearly in Figure 5, is usually described as progressive, assimilatory tonal coarticulation, also known as carryover effects. Xu (2017) has argued that the articulation of a tone begins when the F_0 movement toward its target begins. Therefore, the transitional trajectories seen in Figure 5 are actually part of the target approximation itself, and so they are not due to an overlap (hence coarticulated) with the preceding tone. Indeed, perception evidence suggests that listeners do not discard the initial part of an approaching movement but rather use it to identify the underlying phonetic unit (Fowler & Smith 1986; Gottfried & Suiter 1997; Lee 2000; Xu 1994). For the purposes of the present study, there is no need to differentiate between "transfer of preceding end state to following initial state" and "carryover effects"; we will therefore continue to use the term "tonal coarticulation" for convenience, while recognizing that carryover effects do not necessarily involve true temporal overlap.

The TA model reflects cross-linguistic trends in tonal coarticulation—namely, that the coarticulatory effects with greatest duration and magnitude tend to be both assimilatory and carryover (Brunelle 2009; Xu 1997; Zhang & Liu 2011). Hyman and Schuh (1974) propose that tone spreading (also called "horizontal assimilation") tends to be perseverative (i.e., progressive or carryover) rather than anticipatory (also called regressive); Hyman (2017) reaffirms this. However, Zhang and Liu (2011), who performed a comparison of tonal coarticulation studies in Standard Chinese, Taiwanese, Vietnamese, and Thai, conclude that tonal coarticulation is bidirectional (i.e., progressive and regressive). At the same time, they find that anticipatory effects tend to be language-specific and even tone-specific, may have a weaker and shorter effect, and may be either assimilatory or dissimilatory. Chen, Wiltshire, and Li (2018) update the typology of tonal coarticulation with data from additional languages; they find that, in the majority of the nine languages sampled, carryover effects are (1) greater in magnitude than anticipatory effects and (2) typically assimilatory. However, they also find that anticipatory and carryover effects may be comparable in magnitude in some languages, such as Nanjing Chinese and Malaysian Hokkien.

Tonal coarticulation studies are still relatively rare; for example, tonal coarticulation has not been studied in most of the languages in the Section 3 review. How anticipatory effects may play a role in tone change in the specific languages that show those effects remains an intriguing question. For example, pre-Low Raising is a dissimilatory, anticipatory effect of the raising of a high offset before a Low tone and is seen in Igbo (Liberman et al. 1993), Thai (Gandour, Potisuk, & Dechongkit 1994), Mandarin (Xu 1997), Taiwanese (Peng 1997), and Yoruba (Laniran & Clements, 2003). This effect is akin to Hyman's (2017) polarization rule, which states that H-L sequence intervals tend to expand. This rule would predict that a high offset may be raised over time in languages that show pre-Low raising, a hypothesis that needs to be tested in those specific languages. Another example of anticipatory effects' role in tone change is seen in part of Hyman's (2007) vertical assimilation, when low level before high level becomes mid level; this is one part of the regress to mid pattern seen in Section 3. qTA does not directly model anticipatory effects, because empirical data show that they are much weaker than carryover effects (Xu, 1997), and their exclusion in modeling simulations has no clear adverse effects on perception (Prom-on et al. 2009; Xu & Prom-on 2014). Therefore, anticipatory effects are not included in our modeling in Section 4.

Besides carryover and anticipatory effects, another important source of tonetic variation is truncation, which is also intrinsic to the TA model. Xu (2009) posits that the surface realization of tones is constrained by both minimum movement duration (the minimum time requirement to reach a tonal target) and syllable-bound tonal alignment (in which execution of a tone is synchronized with execution of the syllable). In syllable-tone languages, pitch movements (e.g., falls and especially rises) take a certain minimum amount of time to execute, but the pitch target and its host syllable also have to be articulated in full synchrony with each other, with no freedom for the execution of a tone to go across multiple syllables. Xu and Sun (2002) find that the maximum speed of pitch change is often reached even at a normal speaking rate. Tone-syllable synchronization is therefore like requiring two unequally matched dance partners, one fast and one slow, to complete their respective movements in the same timeframe, with the result that pitch articulators have trouble keeping up with segment articulators (although segments are often truncated as well; see Cheng 2012). The minimum movement duration, when combined with syllable-bound tonal alignment, results in tonal truncation. That is, when a syllable is uttered in too short a time to allow its tone to complete the target approximation process, the later portion of a tone is truncated by the upcoming syllable (Cheng 2012; Xu, 2017). Section 4 discusses the implications of truncation for tone change.

Tone change directionality is an empirical question that calls for evidence of ongoing tone change from many different languages; therefore, we now turn to a cross-linguistic review of studies on tone change-in-progress and recent tone change.

3. Cross-linguistic review of tone variation and change

3.1. Method and Data

The purpose of this review is to examine what types of phonetic tone change occur most often across the (mostly) syllable-tone languages of East and Southeast Asia. Tonal languages from Africa and the

Americas, most of which belong to very different tonal typologies from Asian tone, are left for future research. Studies with two methodological approaches are included: (1) apparent-time studies and (2) analyses of tonal systems that compare their findings with previous (usually decades earlier) analyses of the same location. Studies with sample size less than 5 are excluded. Dialect comparison studies, historical comparative studies, and synchronic variation studies (without an apparent-time component) are also excluded, because they provide only indirect evidence for tone change directionality. Search terms in English and Chinese included "tone variation" (声调变异), "tone change" (声调演变), "generational differences in tone" (代际差异), and "sociophonetic study on tone." Linguistic articles with these key words were searched for in the following database platforms: CNKI (China National Knowledge Infrastructure, 中国知网), Elsevier ScienceDirect, Proquest, JSTOR, Web of Science, Google Scholar, and EBSCOhost. The reference section of eligible articles in the search results and the "cited by" function of Google Scholar were also used to locate additional eligible articles. Articles meeting the eligibility criteria were placed in a database (see Appendix 1).

The database comprises a total of 52 studies on 45 language varieties, with 45 apparent-time studies and 7 across-time comparative studies. Table 1 summarizes the sources of data for the review; Appendix 1 gives the details for each study (including language, reported changes, sample size, and study type). Apparent-time studies are further subdivided into variationist or age-group comparison types. Variationist studies submit data to rigorous statistical testing or modeling (using such tools as ANOVA or regression). Age-group comparison studies compare different age groups' normalized, average pitch trajectories but do not test whether the differences are statistically significant or whether social factors such as age are significant factors. Age-group comparison results are therefore less reliable than those of variationist studies, especially if the sample size is small. Across all apparent-time studies, sample sizes range from 5 to 160 subjects, with an average of 35 subjects and a median of 30.

Table 1: Sources of data in cross-linguistic review of tones

Study type	Studies (*n*)	Number of subjects		
		Range	Average	Median
Apparent-time studies	45	5 – 160	35	30
Variationist	21		40	36
Age-group comparison	24		31	22
Across-time comparative studies	7	*NA*	*NA*	*NA*
Total	52			

The 7 across-time comparative studies included in the review, such as Zhu et al. (2015), are similar to real-time studies, as they compare tonal analyses of the same community across real time, but they do not compare the same speakers across time. In these studies, the contemporary researcher compares his or her results to those of prior researchers. This approach opens up the possibility of "explorers' changes"—i.e., the differences across time may be a function of different researchers' transcription practice and may not reflect actual change. Most studies compare current acoustic analysis to previous researchers' auditory judgment, although one study (Wang 2004) compares current and past impressionistic transcription. We classify all studies in the review according to the strength of the evidence they provide; there are 21 "Type 1" variationist studies, presenting stronger evidence of change, and 31 “Type 2” studies (either age-group or across-time comparison studies, both of which provide weaker evidence of change).

Of the 45 language varieties included in the database, there are 30 Sinitic, 9 Tai-Kadai, 3 Hmong-Mien, and 3 Tibeto-Burman. Two-thirds of the language varieties are Chinese dialects, which could introduce bias; this dominance also reflects the dearth of sociotonetic scholarship on languages other than Chinese. This preliminary review includes only studies that reported changes in the pitch of isolated monosyllables (citation form/单字调); studies on diachronic change in phonation and tone sandhi are left for future research. Tone sandhi is a language-specific process qualitatively distinct from tonal coarticulation (Zhang & Liu 2011). Conditioned and unconditioned changes, including both splits and mergers, are included. It is still an open question whether changes that result in splits or mergers will show the same tone change principles as phonetic tone changes that involve only one tone category. For ease of comparison, whenever a change results in a split or merger, the conditions and tone categories involved are noted in the results tables in Section 3.2.2 and in Appendix 1.

We categorize 97 occurrences of tone change into 43 basic types. Many researchers, though not all, use the 5-level Chao pitch number system to characterize the pitch trajectory before and after the reported change. We code the 5 levels thus: 5 = high; 4 = mid-high; 3 = mid; 2 and 1 = low. [2] was originally coded separately as lower-mid and [1] as low, but lower rising tones (e.g., 13 and 24), regardless of whether they start at [2] or at [1], show the same tendency to become low falling-rising or low level; the difference between them did not seem relevant for diachronic tone change patterns, so rising tones with onsets of either [2] or [1] are combined into “low rising.” For increased transparency, the Chao pitch numbers or prose descriptions used by the original researchers to describe the changes are provided in Tables 3 through 11 in Section 3.2.2 and in Appendix 1. Each of the 43 tone change types is categorized according to what pattern they belong to. Hyman’s (2017) contour simplification and vertical assimilation are referred to as the “leveling pattern” and the “regress to mid” pattern, respectively. Low rising > low level and high falling > high level belong to both the clockwise and leveling patterns; in the review, they are counted as belonging to the clockwise pattern, as they were originally identified in the clockwise tone chain cycle (Zhu et al. 2015).

3.2. Results

3.2.1. Frequently reported tone changes

Figure 6 shows the proportion of various tone change patterns reflected in the tone change types. Of the 43 types, 24 fit the clockwise pattern, 8 are leveling, 4 are regress to mid (labeled “Mid” in Figure 5), 4 are counterclockwise, 2 are the raising of low or mid level tones to high level, and 1 is a lowering of mid level to low level. The vast majority (84%) of the tone change types fit the clockwise, leveling, and regress to mid patterns. Appendix 2 lists all 43 tone change types in the database, in order of frequency (i.e., the number of language varieties in which they are reported to occur).

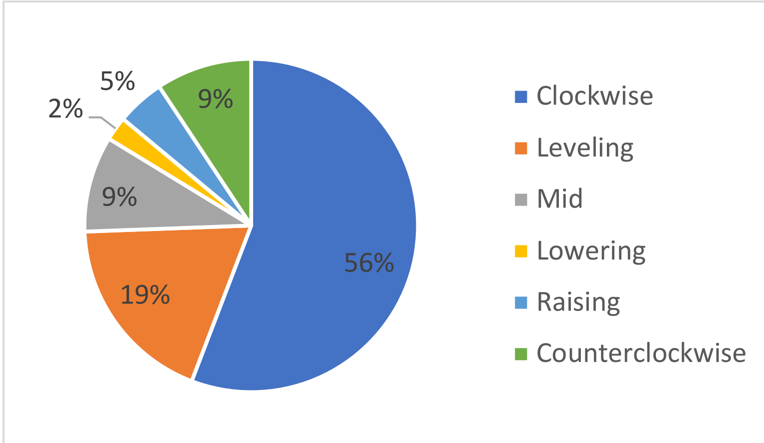


Figure 6: Pie chart of tone change patterns reflected in the 43 tone change types found in the review

Table 2 shows the 15 most frequently reported tone changes; all but one are clockwise changes. The "No. of varieties" column displays the total number of language varieties (not distinguishing language versus dialect) for which the change is reported. The following two columns display how many studies report the change, divided by type of study (i.e., Type 1 or Type 2). When the total number is the same for more than one change, the changes are ranked by number of Type 1 studies. Some languages were the subject of multiple studies, and one study reported the same change occurring in 4 language varieties (delayed rise, line 8 in Table 2; Zhang 2014), so the number of language varieties and the number of studies does not always match. The "Figure 2" column gives the step in the clockwise cycle to which the change belongs, as labeled in Figure 2. The final column indicates the tone change pattern to which the individual change belongs. The top 15 changes occur a total of 63 times, which represents 65% of the 97 change occurrences collated in the review.

Twelve of the top 15 changes occur in more than one language family. The number of asterisks (*) placed after the number of languages represents the number of language families in the database in which the changes appear (i.e., Sinitic, Hmong-Mien, Tai-Kadai, Tibeto-Burman). No change has been reported in all four language families. The presence of just one asterisk means that the change is reported only in Sinitic languages; however, limitation to the Sinitic branch may not reflect a genetic trait, but may rather be due to the relatively low representation of non-Sinitic languages in the database.

Table 2: Top fifteen most frequently reported tone changes. Asterisks (*) after the number denote the number of language families in which the changes appear.

Rank	Change	No. of varieties	Type 1 studies	Type 2 studies	Figure 2 step in the cycle	Pattern
1.	low rise > fall-rise	13**	2*	12**	i > j	Clockwise
2.	high level > high rising	5***	3**	3**	e > g	Clockwise
3.	high falling > high level	5**	3**	2*	d > e	Clockwise/Leveling
4.	mid falling > high falling	5**		6**	c > d	Clockwise
5.	mid rising > mid fall-rise	4**	2*	2**	h > j	Clockwise
6.	low rise-fall > mid/low rising	4**	1*	3**	f > h/i	Clockwise

7.	low falling > mid falling	4**		4**	b > c	Clockwise
8.	low rising > delayed rise	4*	1*		i > almost k	Clockwise/Leveling
9.	low rising offset lowers	3**	3**		i > almost k	Clockwise/Leveling
10.	low fall-rise > low falling	3*	1*	2*	j > b	Clockwise
11.	high falling offset raises	3**	1*	2**	d > almost e	Clockwise
12.	low rising onset raises	3**	1*	2*	i > almost k	Clockwise/Leveling
13.	mid rising > low rising	3**		3**	h > i	Clockwise
14.	low level > mid level	2*	2*		not in Fig. 2	Regress to mid
15.	low rising > low level	2**	1*	1*	i > k	Clockwise/Leveling
	total	63 (65%)				

3.2.2. Results by phonetic tone type

In this section, we answer the question of what changes are most likely to happen to each phonetic tone type by presenting the tone changes reported for each main tone type: high level, high rising, mid rising, low rising, low level, low/mid falling, high falling, rising-falling and falling-rising, and mid level. In Tables 3-11, the beginning state of the tone undergoing change is given in the first row, followed by the end state of the change in the rows below. For each change, the following details are given: the language variety, the tone category undergoing change, the Chao pitch numbers of the result of the change if different from those in the first column, and the study in which the change is reported, divided between Type 1 and Type 2 studies. Tone category abbreviation conventions reflect the original study's usage; "T" followed by a number reflects the numbering format reported by the original source (e.g., T4 = Tone 4 in Bangkok Thai). For Tai-Kadai languages, researchers often use A, B, C, and D for historic tone categories, and this usage is also reproduced in our tables. For studies written in Chinese about Chinese dialects that do not use the above formats, the following abbreviation scheme is used: 1 = *ping* 平; 2 = *shang* 上; 3 = *qu* 去; 4 = *ru* 入; "a" = *yin* 阴 "voiceless initials"; "b" = *yang* 阳 "voiced initials;" "s" = short. For example, "1a" refers to *yinping*, "1b" to *yangping*, etc. The focus here is on phonetic changes, not historical tone categories; therefore, changes are not organized by historical tone category but rather by the beginning state of the tone's phonetic shape. Changes that do not belong to the clockwise, leveling, and mid patterns are marked with an exclamation point, these changes are listed in Appendix 2, lines 17–19, 29, and 42, labeled as either "counterclockwise," "lowering (of mid to low)," or "raising (of low and mid to high)."

3.2.2.1. High level

High level becomes rising or lowers. There is also one example of high level > high falling (a counterclockwise change); it may reflect the reinterpretation of tonal declination (gradual lowering of pitch across an utterance) as a phonological specification.

Table 3: Reported changes to High level tones

Change outcome	No. of varieties	Type 1 studies	Type 2 studies
high level (55) >			

high/mid rising (45/34)	5	Chongqing 1a (Liang & Meng 2011); Qingyun Lalo T1 split> 34/+vd_ (Yang et al. 2015); Bangkok Thai T4 high level > mid rising (Teeranon 2007)	Chongqing 1a (Ming & Zhang 2015); Kouzhai Dong T1 (Zhu et al. 2016); Libo 2ab (Zeng 2005)
high falling (54) (!)	2	Old Beijing 1a offset lowers slightly (Shi & Wang 2006)	Dong'gan 3ab (Liu 2013b)
mid-high level (44)	1	Dali Nisu T4 (Yang & Yang 2018)	
other high-register level tones:			
falsetto high > modal high 66 > 55	1		Xinghua 3a and 4a merge (Zhang & Zhu 2014)
mid-high level > mid level 44 > 33	1		Yueyang 1a (He 2007)
total	10		

3.2.2.2. Mid rising

Mid rising becomes fall-rise or lowers to low rise. In the case of Old Beijing's (Shi & Wang 2006) Tone 1b (*yangping)*, the raising of mid rising's onset creates a fall-rise contour and is thus included in the category of mid rising > fall rise in Table 2 and Appendix 2. Mid rising levels off to mid-high level in one Type 2 study.

Table 4: Reported changes to Mid rising tones

Change	No. of varieties	Type 1 studies	Type 2 studies
mid rising (35/34) >			
fall-rise (215/214)	3	Taiwan Mandarin T2 rising > dipping (Sanders 2008)	Balihan 2a 35>214 (Xue 2013); Khuen Thai (Murng Lang 6 tone system) A12 35>215 (Owen 2012)
low rising (24/224/23)	3		Dong'gan 1b 34>24 (Liu 2013b); Gaotian Zhuang T4 35>224 (Zeng 2001); Tai Phuan A234 35>23 (Akharawatthanakun 2010)
onset raises (introduces fall-rise contour)	1	Old Beijing 1b mid rising onset raises (Shi & Wang 2006)	
35 short > mid-high level (44)	1		Mak [mkg] T7s (Wang 2004)
total	8		

3.2.2.3. Low rising

Low rising becomes fall-rise (the most frequently reported change) or levels off. The changes of delayed rise, onset raising to become flatter, and offset lowering to become flatter reflect various stages in the low rising > low level change. Low rising > low falling follows the clockwise pattern, although it appears to have skipped over the step of low rising > low level > low falling. Low rising > mid level belongs to both leveling and regress to mid patterns. Hong Kong's low rising tone, T5 [23], is now merging with mid rising tone, T2 [25], though the direction of the merger shows a great deal of variation: some speakers merge T2 into T5 while others merge T5 into T2 (Mok & Wong 2010; Mok, Zuo, & Wong 2013). As the result of the merger is still unclear, this change is not included in Table 5.

Table 5: Reported changes to Low rising tones

Change	No. of varieties	Type 1 studies	Type 2 studies
low rising (25/24/23/12/1(1)3/14/15) >			
fall-rise (212/213/214/324/323 325)	13	Taiwanese T2 12>212 (Chiung 2003); Wuxi T4x 113 > 213 (Zhang 2014)	Bangkok Thai Rising A1/T5 (Zhu et al 2015; Pittayaporn 2007, 2018); Khuen Thai (Kang Murng 5 tone system) A12 15>325 (Owen 2012); Mak [mkg] T1 13>312 (Wang 2004); Suzhou 1b 113>213 (Bei 2011); Thai Song Dam A123 13>213 (Burusphat 2011); Chongqing 3ab 25>213 (Ming & Zhang 2015); Jiyang 1a 23>213 (Liu 2017); Keng Tung Shan A123 24>214 (Owen 2012); Kouzhai Dong T9 24>323 (Zhu et al. 2016); Thai Song Dam B123 24 >214 (Burusphat 2011); Wuxi 1b merge to 3b 223>213 (Hu 2007)
delayed rise (13 > 113)	4	4 Shanghai dialects: urban T2/T4/T6 merger and 3 suburban T4/T6 merger (Zhang 2014)	
onset raises (becoming flatter)	3	Bunu T2 (Gong 2018)	Suzhou 4b (Bei 2011); Xi'an 1b (Zhang 2009)
offset lowers (becoming flatter)	3	Changsha 1b (Xiang & Shi 2007); Wuxi T2/T6 merger (Zhang 2014); Bangkok Thai T5 (rising) LH > L(H) (Zsiga 2008)	
low level (22)	2	Dali Nisu TL (Yang & Yang 2018)	Khuen Thai (Kang Murng 5 tone system) B123 13 > merge to B4 22 (Owen 2012)
low/mid falling (21/32)	2		Nancheng 3b 24>32 (Zhang 2015); Tai Phuan A1/T1 23>21 (Akharawatthanakun 2010)
mid level (224 > 33)	1		Mak T6 [mkg] (Wang 2004)
total	28		

3.2.2.4. Low level

Low level becomes falling or regresses to mid. In Nanchang Gan, a short low is merging into a short high, an example of low raising beyond mid to high.

Table 6: Reported changes to Low level tones

Change	No. of varieties	Type 1 studies	Type 2 studies
low level (11/22) >			
low or mid falling (21/31)	2	Hai-Lu Hakka 22>21 (Yeh & Lin 2015)	Keng Tung Shan B123 11 > 31 (Owen 2012)
mid level 33	2	Guangzhou Cantonese T6 merges to T3 (Ou 2012); Hong Kong Cantonese T9 merges to T8 (Zhang, Zhang & Xu 2018)	
low short > high short (!) 2 > 5	1	Nanchang Gan 4b [2] merges to 4a [5] (Cui 2010)	
total	5		

3.2.2.5. Low and mid falling

Low and mid falling onsets both raise, i.e., low falling > mid falling and mid falling > high falling. There are also single changes of mid falling offset raising (a leveling change), mid falling short > high short (clockwise), and mid falling becoming mid fall-rise (counterclockwise).

Table 7: Reported changes to Low and Mid falling tones

Change	No. of varieties	Type 1 studies	Type 2 studies
low falling (21) >			
mid falling (31/421)	total: 4		Chongqing 2b 21>31(Ming & Zhang 2015); Dong'gan T1 21>31 (Liu 2013b); Taipusi 4ab 211>421 (Wei & Cao 2010); Xiaoshuijing Miao T8 21>31 (Yang 2016)
mid falling (31/41/42) >			
high falling (51/52/552/53)	5		Bangkok Thai Falling T3 32>42>552 (Zhu et al. 2015; Pittayaporn 2018); Jining 1ab 41>51 (Wang 2006); Yueyang 3ab 31>51 (He 2007); Gaotian Zhuang T1 42>52 (Zeng 2001); Duyun 4ab merge to 2b 42s>53 (Li 2010)
offset raises	1	Changsha 3ab 42 offset raises (Xiang & Shi 2007	

mid falling short > high short	1		Jiangying Wu 4a 31s > 5 (Liu 2013a)
low fall-rise (213) (!)	1		Jiangying Wu 3b merge to 2b 31>213 (Liu 2013a)
total	8		

3.2.2.6. *High falling*

High falling becomes high level, rise-fall, or rise (all clockwise in directionality). Offset raising is part of the process of high falling becoming high level. In two Type 2 studies, the offset is reported to be lowering, which would be a counterclockwise change.

Table 8: Reported changes to High falling tones

Change	No. of varieties	Type 1 studies	Type 2 studies
high falling (51/52/53) >			
high level 55	5	Dalian 1a (Gao 2018); Lanzhou 1a (Yi 2016); Bangkok Thai Falling (T3) HL > H (Zsiga 2008)	Jining 2ab 52>55 (Wang 2006); Chaohu 3ab 52>55 (Xing 2008)
offset raises	3	Old Beijing 3ab (Shi & Wang 2006)	Bangkok Thai Falling T3 (Thepboriruk 2009); Xi'an 2ab 51>52 (Zhang 2009)
offset lowers (!)	2		Gaotian Zhuang T1 42 & T3 53 > 52 (Zeng 2001); Xiaoshuijing Miao T1 52>51 (Yang 2016)
mid rise-fall	1	Chongqing T3 (Liang & Meng 2011)	
mid rising; 53 > 445	1		Penang Hokkien 3a (Hing 2018)
total	12		

3.2.2.7. *Rising-falling*

Rising-falling becomes rising or levels off. In two studies (Bei 2011; Gong 2018), the onset of a low rising-falling tone raises to mid, resulting in a mid falling tone (231 > 331).

Table 9: Reported changes to Rising-falling tones

Change	No. of varieties	Type 1 studies	Type 2 studies
high rise fall (453) >			
high rising 45	1		Mien-Yao T3 (L-Thongkum 1997)
mid-high level 44	1	Yangliu Lalo TL&H (Yang, Stanford, Liu, Jiang, & Tang in press)	
low rise-fall (243/232/231) >			
mid or low rising (13/113/24/34)	4	Wuxi T4x 232 > 113 (> 213) (Zhang 2014)	Jining 3ab 232 > 24 (Wang 2006); Lanzhou 3ab 232 > 13 (Zhang

			2012); Mien-Yao T4 232 merge to 34 (L-Thongkum 1997)
flatter 243 > 232	1		Thai Song Dam A4 (Burusphat 2011)
onset raises 231 > 331	2	Bunu T4 (Gong 2018)	Suzhou 3b (Bei 2011)
total	9		

3.2.2.8. Falling-rising

Similar to rising-falling tones, the second pitch movement of falling-rising tones tends to elide, leaving only a fall. In most cases, the pitch level of the tonal onset remains stable, e.g., low fall-rise > low/mid falling, but there is one case (Qi 2011, Zhaoyuan Chinese) where the low fall-rise shows a change to high falling (212 > 52). There are also two counterclockwise examples of falling-rising becoming rising, but both examples are reported in Type 2 across-time comparison studies.

Table 10: Reported changes to Falling-rising tones

Change	No. of varieties	Type 1 studies	Type 2 studies
high fall-rise (512) >			
offset lowers	1		Suzhou 3a (Bei 2011)
mid fall-rise (434/323) >			
mid fall (434 > 41)	1		Jiangying Wu 3a merge to 1a (Liu 2013a)
mid level (323 > 33)	1		Zhaoyuan 1a merge to 2ab (Qi 2011)
low fall rise (212/213) >			
low falling (21/211)	3	Taiwan Mandarin T3 dipping becomes falling (Sanders 2008)	Libo 3ab 113>213>21 (Zeng 2005); Taipusi 3ab 213>211 (Wei & Cao 2010)
low rising (13/224) (!)	2		Gaotian Zhuang T6 213>224 (Zeng 2001); Jiangying Wu 2b merge to 1b 213>13 (Liu 2013a)
onset raises, pivot point moves later	1	Old Beijing 2ab (Shi & Wang 2006)	
high falling (52)	1		Zhaoyuan 3a 212>52 (Qi 2011)
total	10		

3.2.2.9. Mid level

In the database, mid level is the beginning state of the change in only three instances, but is the end state in 12. From this asymmetry, we can postulate that the mid level tone tends to be relatively inert itself but is an appealing target for other tones to merge with. Note that this result contrasts with Zhu's (2018) "mid level radiation rule" in which mid level is predicted to change into other tones.

Table 11: Reported changes to Mid level tones

Change	No. of varieties	Type 1 studies	Type 2 studies
mid level (33) >			
mid-high level (!) 44	1		Xiaoshuijing Miao mid level overall raise to mid-high level (affects T4, T5, T7) (Yang 2016)
low falling (!) 21	2	Taiwanese T5 33 > 21 (Yeh & Tu 2012)	Yueyang 2b 33 > 21/vd_ (He 2007)
total	3		

3.2.3. Summary of results

The cross-linguistic review reveals a dominant, though not absolute, clockwise directionality: high level > mid rising; mid rising > falling-rising or low rising; low rising > falling-rising or low level; low level and falling-rising > low falling; low falling > mid falling; mid falling > high falling; high falling > high level. Another significant trend, though less frequent than the clockwise pattern, is the flattening out of contour tones, the leveling pattern.

Table 12 summarizes these results, with lines 1–7 organized in a sequential order that first lists the beginning state of a tone type, followed by its most common change result. The changes are classified according to what pattern they fit ("Clockwise pattern" and "Leveling & mid patterns"). Low rising > low level and high falling > high level belong to both the clockwise and leveling patterns; they are listed here only in the clockwise pattern column, as they were originally identified in the clockwise tone chain cycle of Zhu et al. (2015). The No./Total, % column shows the number of times a particular change is reported, divided by the total number of changes reported for that tone type; this fraction is followed by the percentage equivalent. For example, for high level, 10 occurrences of change are reported. Of those 10 changes, 5 of them are high level > high/mid rising [45/35/34]; therefore, 50% of the time a change is reported for high level, it changes to high/mid rising. The ordering in Table 12 is not meant to imply that all tones will eventually merge together. Instead, the cyclicity suggests that an individual tone may eventually proceed through all stages in this cycle, possibly merging—or not merging—with other tones along the way.

Table 12 does not include the raising beyond mid, lowering beyond mid, and counterclockwise patterns, because such patterns occur only rarely. The Raising of mid to high and low to high occur only once each; lowering of mid to low occurs twice; counterclockwise changes (e.g., high level > high falling) occur 7 times. In terms of frequency of occurrence, these three minor patterns together account for 11% of the 97 reported tone changes. They are also only a small proportion of the 43 tone change types listed in Appendix 2.

Table 12: Summary of results

	Begin state	Clockwise pattern	No./Total, %	Leveling & mid patterns	No./Total, %
1	high level	> high/mid rising	5/10, 50%	lowers to mid	3/10, 30%
2	mid rising	> fall-rise	4/8, 50%		
		> low rising	3/8, 43%		

3	low rising	> low level (levels off)	14/28 50%		
		> fall-rise	13/28, 46%		
4	low level	> low/mid falling	2/5, 40%	raises to mid	2/5, 40%
5	low falling	> mid falling	4/4, 100%		
6	mid falling	> high falling	5/8, 63%	levels off	2/8, 25%
7	high falling	> high level (levels off)	8/12, 67%		
		> mid rise-fall	1/12, 8%		
	rise-fall	> rising	5/9, 55%	levels off	2/9, 22%
	fall-rise	> falling	7/10, 70%	levels off	1/10, 10%
	mid level			lowers (!)	2/3, 66%

4. Discussion

Section 3 addressed the question of directionality in diachronic tone change through a review of tone change studies in East and Southeast Asia. This section addresses the question of underlying mechanisms: what could account for the cross-linguistic trends of clockwise, leveling, and mid patterns?

A common feature in the clockwise and leveling patterns is the seeming rightward sliding of pitch movements' temporal alignment, such as the rightward sliding of the peak in Bangkok Thai's Tone 4 (Figure 1, [2]-[3]-[5]) and the truncation of Tone 5 (Figure 1, [6]). We begin by examining the rightward sliding of pitch movements, but we then go on to suggest that both types of changes can be attributed to a common articulatory mechanism, namely the truncation of tone production due to time pressure.

In the clockwise pattern, the retiming of pitch movements matches Carroll's (2010) "temporal realignment" process: (1) carryover effects from preceding tones slide rightward, taking up a larger portion of the syllable; (2) all following pitch movements are pushed rightward, eventually eliding completely. In the leveling pattern, the pitch movements in the offset become so delayed that eventually they elide (cf. Pittayaporn's contour reduction mechanism). The only difference between clockwise and leveling changes is whether the carryover effects slide rightward; in most (but not all) leveling changes, the pitch onset remains stable and carryover effects do not appear to slide right. Table 13 breaks down the most commonly occurring tone changes according to whether they show both carryover effects and following pitch movements sliding rightward, or only the latter. Note that peak delay is a subtype of rightward sliding, and that rightward sliding encompasses any pitch movement, not just peaks.

Table 13: Analysis of tone changes as retiming of pitch movements

Tone	Change	Carryover effects slide right	Following pitch movements slide right (or even elide)
high level	> high/mid rising	+	+ (peak delay)
mid rising	> low rising	+	+
mid rising	> fall-rise	+	+
low rising	> fall-rise	+	+
low level	> low/mid falling	+	+

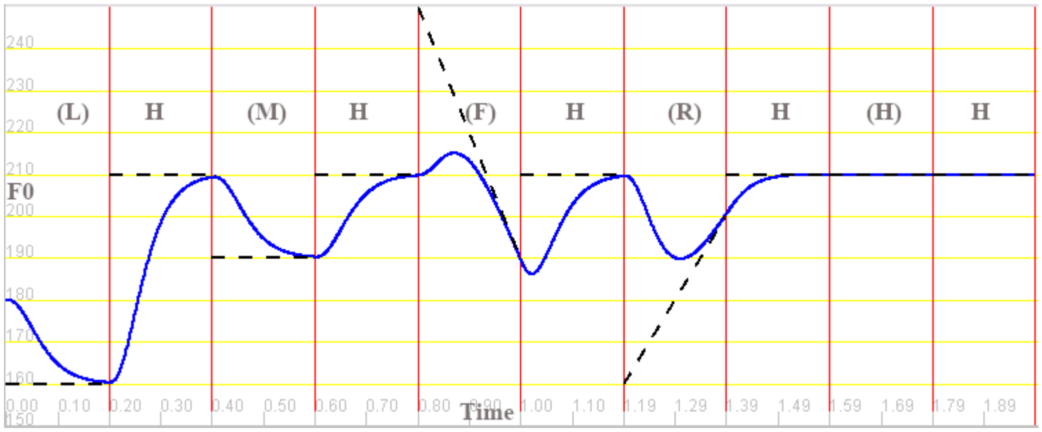
low falling	> mid falling	+	+
mid falling	> high falling	+	+
high falling	> mid rise-fall	+	+ (peak delay)
low rising	> low level	-	+ (contour reduction)
high falling	> high level	-	+ (contour reduction)
mid falling	> mid level	-	+ (contour reduction)
rise-fall	> rising	-	+ (contour reduction)
fall-rise	> falling	-	+ (contour reduction)
low level	> mid level	-	- target undershoot
high level	> mid level	-	- target undershoot

We propose that a common mechanism, truncation, may underlie all the changes listed in Table 13, whether or not apparent rightward sliding is involved. First, let us consider examples of how tone production in connected speech, which is conceived of as a target approximation process (Section 2.2), generates a pool of tonal variants. Figure 7 shows the simulated surface realizations of various tones when preceded by other tones. These contours are generated by the interactive demonstration of the quantitative TA model developed by Prom-on et al. (2006), a tool that simulates tones and intonation in connected speech (accessible at http://www.homepages.ucl.ac.uk/~uclyyix/qTA/). Default values in the web program were used for all parameters (duration, strength, initial pitch, pitch slope and height for the respective tones, and upper and lower bounds of pitch). It is also possible to specify parameters if those are known for a specific language, but here we are initially aiming at a generic model simply for illustrative purposes.

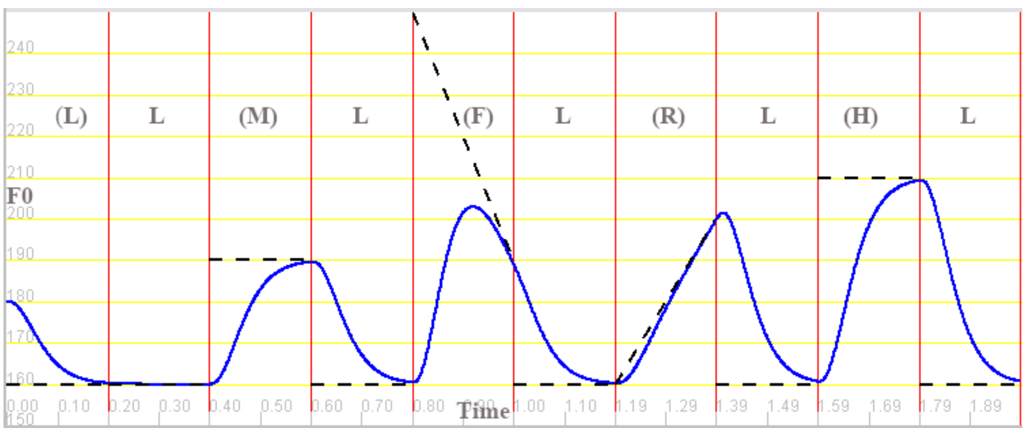
Suppose that a hypothetical syllable-tone language has five tones: L(ow), M(id), H(igh), R(ising) and F(alling). Figure 7 shows surface realizations of (a) H, (b) L, (c) R, and (d) F when following L, M, F, R, and H, respectively. Note the most commonly occurring tone contour for each tone: High is realized with a rising contour in 4 of 5 sequences; Low with a falling contour in 4 of 5 sequences; Rising with a falling-rising contour in 4 of 5 sequences; and Falling with a rising-falling contour in 4 of 5 sequences. The surface realization of Low after another Low is simply a low level tone, but following M, H, R, and F tones, Low takes on a falling pitch trajectory, because its pitch onset is determined by the non-low pitch offset of the preceding tone. This implies that, even if some of the sequences only rarely occur in free speech, Low is still likely to be realized with a fall on most occasions when it is uttered. In fact, this phenomenon has already been observed by tonologists. Yip (2001) states that "the lowest tone in the system nearly always involves a slight fall." Likewise, for rising tones, Zhu (2010: 278) notes that rising tones usually begin with a slight dip followed by a rise (that is, they are realized with a falling-rising contour).

Based on the qTA modeling, we can hypothesize that if the preceding tonal offset is already at the following tone's onset height (e.g., a high tone high preceded by a tone with a high offset), the tone will be realized with a shape similar to its canonical form. But if the preceding tonal offset is from the opposite register (e.g., a high preceded by a low, or a low preceded by a high), then the carryover effect will have an impact on the shape of the following tone's pitch trajectory: high tones will be realized as rising, low tones as falling. Similarly, if a rising or falling tone is preceded by an offset that is different from its onset, a preparatory movement will be required as part of the approximation to the dynamic target: for rising tones, first a fall and then a rise; for falling tones, first a rise and then a fall.

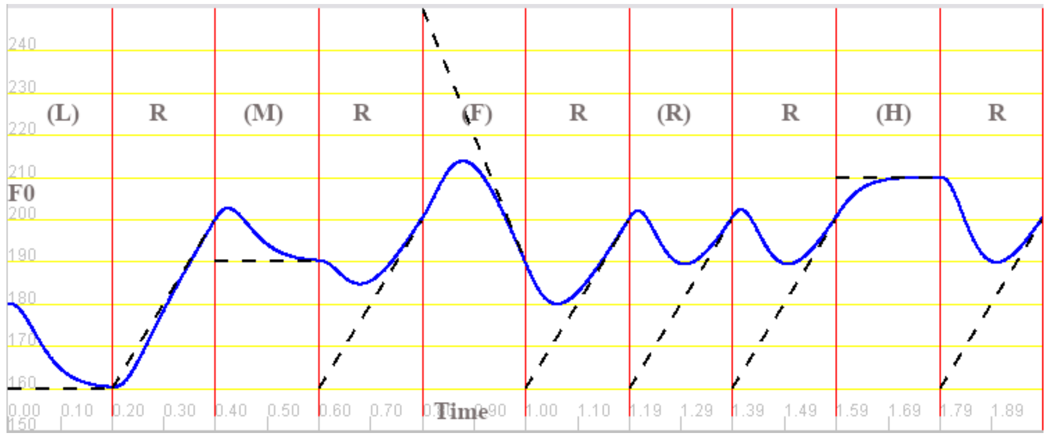
(a) High tone contextual variation:



(b) Low tone contextual variation:



(c): Rising tone contextual variation:



(d): Falling tone contextual variation:

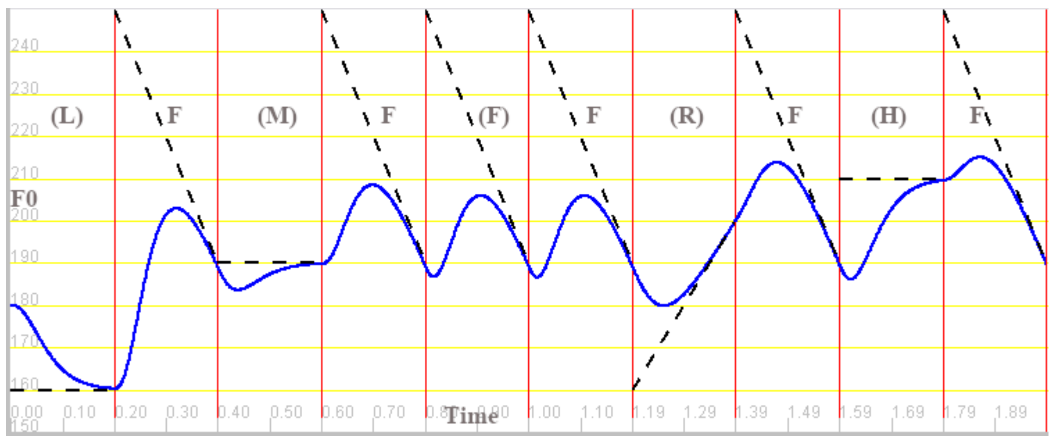


Figure 7: Simulated surface realizations of (a) H, (b) L, (c) R, and (d) F when following L, M, F, R, and H, respectively, generated by the quantitative TA model interactive tool (Prom-on et al. 2006). Blue lines represent pitch trajectory; dashed lines represent underlying pitch targets; red vertical lines represent syllable boundaries. The y-axis is F_0 (Hz) and the x-axis is time (s).

Despite the extensive amount of contextual tone variation, the underlying tonal targets in Figure 7 represented by the dashed lines are all virtually attained by the end of each syllable, i.e., the solid surface F_0 curves always fully converge with the dashed lines. When a syllable is spoken in only half the time of those shown in the figure, however, only the first half of each solid curve is completed. The resulting practice can be called truncation, or premature termination of tonal target approximation under time pressure.

Figures 8 and 9 provide examples of how truncation may lead to what appears to be either peak delay (Figure 8) or contour reduction (Figure 9; both figures generated with the qTA model, parameters specified at top). In Figure 8’s first sequence of M-H-L (at left), the H is given sufficient time to approach its target of high level. But in the second sequence (at right), the H is not given sufficient time, which results in premature termination of the movement toward H. This truncated H shows only a continuous rise that takes up the entire duration of the syllable, thus appearing much more like a rising tone. Figure 9 illustrates how a high falling tone may become more level when truncated. As in Figure 8, the only difference between the high falling tone in the first sequence and the second sequence is the duration of the middle syllable. The truncated falling tone on the right has less pitch excursion than the non-truncated one on the left, resulting in a more level trajectory. In this account, therefore, both peak delay and contour reduction are due to a common root mechanism, rather than being two separate mechanisms themselves.

We suggest that, if the truncated version of the tone occurs often enough, listeners, especially if they are unfamiliar with the language (e.g., children or L2 learners), will eventually reinterpret the truncated variant as the speaker's intended target. This would lead to the intriguing possibility of a unified account of both clockwise and leveling patterns. Truncation creates new tonal variants by maintaining only the early portion of the target approximation movement, leaving out the final convergence to the underlying target. The diachronic result is elision of the final pitch movement and a novel shape associated with a novel underlying target. In a truncated rise-fall, the rise may extend beyond the halfway point, and the fall may be cut short or even completely elided. This is in fact what usually happens to rising-falling tones—they become rising tones in most cases. In other words, truncation creates synchronic variants that look very much like the rightward sliding of pitch targets seen in the clockwise and leveling patterns. It is possible that truncation may even play a role in the regress to mid pattern: under time pressure, target undershoot occurs, which means that a high or low level tone will be realized closer to the speaker's mean F_0, opening the way to phonologization of the level tone as a mid level tone.

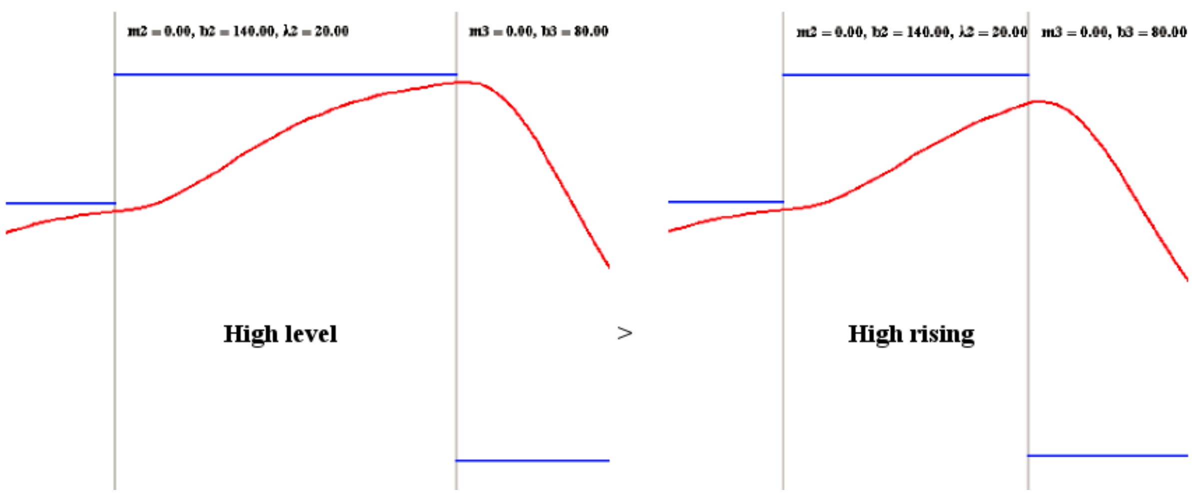


Figure 8: High level becomes more like high rising when truncated. Tone sequence of Mid-High-Low; second repetition of the sequence is truncated. m = slope, b = pitch height, λ = target approximation rate. Diagram generated by qTA model (Prom-on et al. 2006).

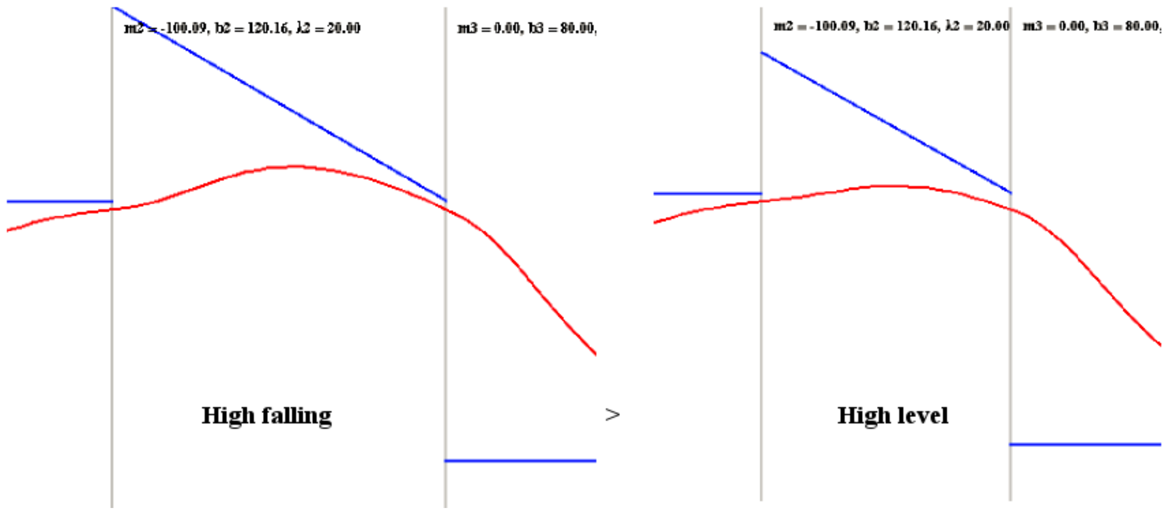


Figure 9: High falling becomes more like high level when truncated. Tone sequence of Mid-Falling-Low; second repetition of the sequence is truncated. m = slope, b = pitch height, λ = target approximation rate. Diagram generated by qTA model (Prom-on et al. 2006).

Syllable shortening actually occurs more frequently in natural speech than is generally seen in typical tone studies, where tones are usually observed in their canonical forms either in isolation or in positions that would receive prominence. In connected speech, many syllables occur in word-initial or word-medial positions where the duration tends to be much shorter than word-, phrase- or sentence-final positions (Xu, 2009). The condition for tonal truncation is therefore likely a common occurrence. As for whether a truncated tone can be heard as one with a different tonal target, this possibility can be tested empirically in perception experiments. Computational modeling tools based on the qTA model (Prom-on et al. 2009) can be used in these studies to generate perceptual stimuli that simulate the truncation process.

Further research is needed in many areas of tone change. Phonetic change in sandhi forms (as opposed to citation forms) has thus far been explored in only a handful of studies (e.g., Zhang & Liu 2011). This paper has focused on the origins of phonetic change in individual tones, as opposed to the connections between changes in multiple tones across a tone system. Phonetic changes that are part of tone chain shifts are predicted to follow clockwise/leveling patterns, like those seen in Bangkok Thai across the last century. However, we have not addressed what factors influence whether tones merge as they change.

Foregrounding the role of synchronic variation of tones in connected speech encourages reexamination of the role of segment-pitch interaction and language contact, the most frequently cited motivations for tone change. Most of the changes in the cross-linguistic review were not conditioned by pre- or postvocalic segments, but when segment-pitch interaction did play a role, the change still conformed to the common patterns. For example, voiced initial consonants depress the tonal onset of a high level tone down in Qingyun Lalo (Yang et al. 2015), creating a mid rising tone. But four other languages report the same change *without* segment-pitch interaction playing a determining role. Likewise, changes attributed to language contact also showed clockwise directionality; for example, L-Thongkum (1997) suggests that the changes in Mien Yao (high rise-fall > high rise and low rise-fall > low rise) are due to contact with Thai, but such changes also fit the trend of tonal offsets eliding. The results of our review suggest that timing constraints inherent in the target approximation process determine the directionality of the change, whereas segment-pitch interaction and contact may interact with the change, obstructing it or moving it forward.

Future research may also take into consideration other factors, many of them language-specific, that would interact with tone production. These could include factors that affect syllable duration as a function of position in word and phrase (Xu 2009; Xu & Wang 2009), which may affect the severity of truncation, and factors that affect voice onset time of syllable initial consonants, which may determine the amount of initial F_0 movement in a tone audible to the listener. These factors may further determine which tone changes happen in a particular language, as can be simulated by the TA model.

5. Conclusion

Tone change is complex and unpredictable, but this study shows that it is not random or inexplicable. Rather, our review of 52 tone change studies on Sinitic, Tai-Kadai, Hmong-Mien, and Tibeto-Burman languages found surprisingly strong cross-linguistic tendencies in tone change directionality. The vast majority of the observed tone changes fit into clockwise, leveling, or regress to mid patterns. In most cases, phonetic changes that resulted in splits or mergers followed the same trends as phonetic changes that involved only one tone. Other patterns have also been reported, such as counterclockwise, raising of low and mid level tones to high, and lowering of mid level to low level, but such patterns are infrequent and appear generally in Type 2 studies. Whether these changes can be verified, along with what factors may have triggered them, is left for future research.

Clockwise and leveling patterns both show a gradual sliding of pitch movements from left to right (and eventually right off the end of the syllable). But merely naming the rightward sliding phenomenon is not enough; we must also consider what causes the sliding effect. When tones are truncated in connected speech, as we have suggested, their surface realizations also show the sliding effect: the end is cut off, the middle becomes the end, and the beginning extends into the middle. The clockwise and leveling patterns of tone change mirror the synchronic variation caused by truncation. We therefore propose that temporal realignment triggered by synchronic truncation shapes the majority of tone changes in syllable-tone languages. Regress to mid changes, the result of target undershoot in connected speech, is probably also due to the timing constraints inherent in the tonal approximation process. The demonstration of role of truncation in a particular ongoing tone change is beyond the scope of this paper, but the striking parallel between truncated variants and results of tone change opens up the possibility of a unified account for clockwise, leveling, and regress to mid patterns. We therefore encourage further research on the role of truncation as a mechanism in tone variation and change.

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Appendix 1: Studies in the cross-linguistic review

1. Type 1 studies (ordered by language); splits and mergers marked with (*)

Language(s)	Study	Language Family	Reported change(s)	Sample size	Type
Bunu	Gong 2018	Hmong-Mien	T2 low rise onset raises; T4 mid rise-fall onset raises	12	variationist
Qingyun Lalo	Yang et al. 2015	Tibeto-Burman	high level splits to mid rising after voiced initials and high level elsewhere*	38	variationist
Yangliu Lalo	Yang et al. 2018	Tibeto-Burman	high rise-fall becomes mid-high level	63	variationist
Dali Nisu	Yang & Yang 2018	Tibeto-Burman	13> 22; 55 > 44	26	variationist
Bangkok Thai	Zsiga 2008	Tai-Kadai	falling (T3) HL > H; T5 (rising) LH > L(H)	10	variationist
Bangkok Thai	Teeranon 2007	Tai-Kadai	T4 (high): high level > mid rising	15	variationist
Guangzhou Cantonese	Ou 2012	Sinitic	T6 (low level) moves up to T3, merged tone is mid-level*	75	variationist
Hong Kong Cantonese	Mok & Wong 2010	Sinitic	T2 25 & T5 23 bidirectional merger	17	variationist
Hong Kong Cantonese	Zhang, Zhang, & Xu 2018	Sinitic	Tone 9 low level moves up to merge with Tone 8*	50	variationist
Nanchang Gan	Cui 2010	Sinitic	2 > 5; Ru tonal merger: [5] and [2] merging to [5]*	40	variationist
Hai-Lu Hakka	Yeh & Lin 2015	Sinitic	low-level tone > low-falling tone	32	variationist
Old Beijing Mandarin	Shi & Wang 2006	Sinitic	1a high level offset lowers; 1b mid rising onset raises; 2ab fall-rise onset raises, dipping pivot point moves later; 3ab high falling offset raises	52	variationist
Chongqing Mandarin	Liang & Meng 2011	Sinitic	T1 "rise" feature is more remarkable; T3 "convex" shape is forming	30	variationist
Dalian Mandarin	Gao 2018	Sinitic	high falling > high level	106	variationist
Lanzhou Mandarin	Yi 2017	Sinitic	1a high falling > high level; merger of 2ab and 3ab*	36	variationist
Lipo Mandarin	Zeng 2005	Sinitic	2ab 55 > 45; 3ab (113 >) 213 > 21	17	variationist
Taiwan Mandarin	Sanders 2008	Sinitic	T2: 35 > 325, rising to dipping; T3 213 > 21, dipping to falling	33	variationist
Taiwanese Min	Chiung 2003	Sinitic	T2: 12 > 212, low rising to falling-rising	30	variationist

Taiwanese Min	Yeh & Tu 2012	Sinitic	T5 33 > 21 in production errors	45	variationist
Shanghai dialects; Wuxi	Zhang 2014	Sinitic	BSD and SJD rising T4/6 and Wuxi T2/6 decreasing steepness; 4 dialects show delayed rising 13 > 113; Wuxi TX4: low rise fall > low rise > low fall rise	Shanghai = 80; Wuxi = 40	variationist

2. Type 2 studies (ordered by language); splits and mergers marked with (*)

Language	**Language Family**	**Study**	**Researchers' interpretation**	**Sample size**	**Type**
Xiaoshuijing Miao	Hmong-Mien	Yang 2016	T1: 52 > 51; T2: 13 > 23; mid level overall rise to mid-high level (affects T4, T5, T7); T8 21 > 31	36	age-group comparison
Mien-Yao	Hmong-Mien	L-Thongkum 1997	T4 232 merge to 34*; T3 453 > 45	19	age-group comparison
Bangkok Thai	Tai-Kadai	Pittayaporn 2018	see Figure 5	NA	comparative
Bangkok Thai	Tai-Kadai	Zhu et al. 2015	C12/T3 32 > 42 > 552. C3/T4 553 > 55/45. A1/T5 35/24 > 324/314/303	NA	comparative
Bangkok Thai	Tai-Kadai	Thepboriruk 2009	Bangkok Thai Falling T3 offset raises	25	age-group comparison
Gaotian Zhuang	Tai-Kadai	Zeng 2001	T1 42 & T3 53 > 52; T4 35 & T6 213 > 224	NA	comparative
Khuen Thai (Kang Murng 5 tone system); Khuen Thai (Murng Lang 6 tone system); Keng Tung Shan	Tai-Kadai	Owen 2012	Kang Murng B123 13 > merge to B4 22*; A12 15 > 325; Murng Lang A12 35 > 215; Shan A123 24 > 214; B123 11 > 31	NA	comparative
Tai Phuan	Tai-Kadai	Akharawatthanakun 2010	A1 23 > 21; Mid-rising > Low-rising	15	age-group comparison
Thai Song Dam	Tai-Kadai	Burusphat, S. 2011	A123 13 > 213; B123 24 > 214; A4 243 > 232	6	age-group comparison
Kouzhai Dong	Tai-Kadai	Zhang, Wei, & Wang 2016	T1 55> 45; T9 24 > 323	NA	comparative
Mak	Tai-Kadai	Wang 2004	T1 13 > 312; T6 224 > 33; T7 35 short > 44/55	NA	comparative
Balihan	Sinitic	Xue 2013	2a 35 > 214	60	age-group comparison
Changsha	Sinitic	Xiang & Shi 2007	1b 13 > offset lowers; 3ab 42 offset raises	67	age-group comparison
Changsha	Sinitic	Zhou 2013	same as Xiang & Shi 2007	5	age-group comparison

Chaohu	Sinitic	Xing 2008	3ab 52/54 > 55	10	age-group comparison
Chongqing	Sinitic	Ming & Zhang 2015	1a 445 > 55 > 45; 3ab 24 > 213; 2b 21 > 31; 2ab 42 > 341	10	age-group comparison
Dong'gan	Sinitic	Liu 2013b	1a 21 > 31; 1b 34 > 24; 3ab 55/44 > 54	7	age-group comparison
Duyun	Sinitic	Li 2010	merger of 4ab with 1b: 42short > 53 modal*	160	age-group comparison
Jiangying Wu	Sinitic	Liu 2013a	2b 213 > 1b 13; 3b merge to 2b 31 > 213; 4a 31s > 5; 3a merge to 1a 434 > 41*	NA	comparative
Jining	Sinitic	Wang 2006	1ab 41 > 51; 2ab 52 > 55; 3ab 232 > 24; 4ab 42s > 52s	5	age-group comparison
Jiyang	Sinitic	Liu 2017	1a 23 > 213	30	age-group comparison
Lanzhou	Sinitic	Zhang 2012	2ab/3ab merger 232 > 13*	30	age-group comparison
Nancheng	Sinitic	Zhang 2015	3b 24 merger to 3a 32*	50	age-group comparison
Penang Hokkien	Sinitic	Hing 2018	53 > 445	12	age-group comparison
Suzhou	Sinitic	Bei 2011	1b 113 > 213; 3b 231 > 331; 3a 512 offset lowers; 4b 13>23	57	age-group comparison
Taipusi	Sinitic	Wei & Cao 2010	3ab 213 > 211; 4ab 211 > 421	8	age-group comparison
Wuxi	Sinitic	Hu 2007	2ab 223 > 213	40	age-group comparison
Xi'an	Sinitic	Zhang 2009	1b 24 > 34; 2ab 51>52	47	age-group comparison
Xinghua	Sinitic	Zhang & Zhu 2014	3a and 4a 66 falsetto merge to 55 high modal*	7	age-group comparison
Yueyang	Sinitic	He 2007	1a 44 > 33; 3ab 31 > 51; 2b 33 > 21/vd_	32	age-group comparison
Zhaoyuan	Sinitic	Qi 2011	1a 323 > 2ab 33; 3a 212 partial merge to 3b 52*	6	age-group comparison

Appendix 2: Tone changes reported in the studies

	Change	No. of varieties	Type 1 studies	Type 2 studies	Pattern
1.	low rise > fall-rise	13**	2*	12**	Clockwise
2.	high level > high rising	5***	3**	3**	Clockwise
3.	high falling > high level	5**	3**	2*	Clockwise/Leveling
4.	mid falling > high falling	5**		6**	Clockwise
5.	low rise-fall > mid/low rising	4**	1*	3**	Clockwise
6.	mid rising > mid fall-rise	4**	2*	2**	Clockwise
7.	low falling > mid falling	4**		4**	Clockwise
8.	low rising > delayed rise	4*	1*		Clockwise/Leveling
9.	low rising offset lowers	3**	3**		Clockwise/Leveling
10.	low fall-rise > low falling	3*	1*	2*	Clockwise
11.	high falling offset raises	3**	1*	2**	Clockwise
12.	mid rising > low rising	3**		3**	Clockwise
13.	low rising > low level	2**	1*	1*	Clockwise/Leveling
14.	low level > mid level	2*	2*		Regress to mid
15.	low rising onset raises	3**	1*	2*	Clockwise/Leveling
16.	low level > low/mid falling	2**	1*	1*	Clockwise
17.	low rise-fall onset raises to mid	2**	1*	1*	Leveling
18.	mid level > low falling (!)	2*	1*	1*	R3 lowering
19.	high level > high falling (!)	2*	1*	1*	Counterclockwise
20.	high falling offset lowers (!)	2**		2**	Counterclockwise
21.	low fall-rise > low rising (!)	2**		2**	Counterclockwise
22.	low rising > low/mid falling	2**		2**	Clockwise
23.	low rising onset raises (24 > 34)	2*		2*	Leveling
24.	high level > mid-high level	1*	1*		Regress to mid/R3 lowering
25.	low short > high short 2 > 5	1*	1*		Raising
26.	mid falling offset raises	1*	1*		Leveling
27.	high falling > mid rise-fall	1*	1*		Clockwise
28.	high rise-fall > mid-high level	1*	1*		Leveling
29.	low fall-rise onset raises, pivot point moves later	1*	1*		Clockwise
30.	mid falling short > high level short	1*		1*	Clockwise
31.	mid falling > low fall-rise (!)	1*		1*	Counterclockwise
32.	mid fall-rise > mid fall	1*		1*	Clockwise

33.	falsetto high > modal high	1*		1*	Regress to mid/R3 lowering
34.	mid-high level > mid level	1*		1*	Regress to mid/R3 lowering
35.	mid rising short > mid-high level	1*		1*	Leveling
36.	low rising > mid level (224 > 33)	1*		1*	Leveling
37.	high falling > mid rising	1*		1*	Clockwise
38.	high rise-fall > high rising	1*		1*	Clockwise
39.	low rise-fall > flatter	1*		1*	Leveling
40.	high fall-rise offset lowers	1*		1*	Clockwise
41.	mid fall-rise > mid level	1*		1*	Leveling
42.	low fall-rise > high falling	1*		1*	Clockwise
43.	mid level > mid-high level (!)	1*		1*	Raising